

IMPLEMENTING REAL TIME RATINGS FOR PATH 15

CONSULTANT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to \$62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/ Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

What follows is the final report for Implementing Real Time Ratings on Path 15, Contract Number 700-00-006, conducted by The Valley Group, Inc. This report is entitled *Implementing Real Time Ratings on Path 15*. This project contributes to the Energy Systems Integration program.

For more information on the PIER Program, please visit the Energy Commission's Web site at: <http://www.energy.ca.gov/pier/index.html> or contact the Energy Commission's Publications Unit at 916-654-5200.

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Abstract

California's Path 15 is the main transmission interface between northern and southern California. Under the most favorable conditions, Path 15 has a maximum pre-contingency path capability of 3400 MW. In many cases, this capability is not sufficient, causing the path to become a key cause of congestion in California. For instance, the cost of Path 15 constraints in the fourth quarter of 2001 was as high as \$300 million.

A 10% useful rating increase in circuits of Path 15 amounts to a post-contingency increase of 45-55 MW per circuit. But because these circuits carry only a part of the total path power flow, the resulting increase in pre-contingency capability could be up to 500 MW higher than the present limit. Such increases, for instance through real time rating of the transmission lines, could have major economic benefits.

To implement real time ratings on Path 15, CAT-1 Transmission Line Monitoring Systems were installed at two sites on Gates-Panoche circuits 1 and 2, whose ratings are the primary limitations for post-contingency power transfer. Algorithms allow PG&E's EMS system to calculate the absolute conductor temperatures, temperature rises, and steady state ratings of the circuits, which are then sent to the Path 15 rating computer.

Both the physical limitations of the lines and the system operating limitations were studied extensively. Because of the extreme importance of Path 15 reliability considerations, the real time ratings will only be used operationally after an extended offline experience. CAISO wants to study a number of other higher contingency path limitations to determine what the new maximum contingency limitation of the path would be.

Key words: Path 15, transmission, line, circuit, rating, real time rating, economic, congestion, contingency, ATC.

Executive Summary

Background and Overview

California's Path 15 is the main transmission interface between northern and southern California. It is the most fundamental limitation for electric transactions within California under several different economic and seasonal conditions. At present, the transmission lines that make up Path 15 are thermally rated assuming a maximum (emergency) temperature of 100°C, a 2 ft/sec crosswind, an ambient temperature adjusted in three steps, and a difference for day and night ratings. Under the most favorable conditions, this amounts to a maximum pre-contingency path capability of 3400 MW. In many cases, this capability is not sufficient, causing the path to become a key cause of congestion in California. Particularly during 2001, Path 15 caused frequent economical constraints. The cost of Path 15 constraints in the fourth quarter of 2001 was estimated to be at least \$60 million and possibly as high as \$300 million.

Thus, there is great interest in increasing the capability of Path 15, due to the large cost impact of the present constraints. For instance, a 10% useful rating increase of Pacific Gas & Electric's (PG&E) Gates-Panoche circuits of Path 15 amounts to a post-contingency increase of 45-55 MW per circuit. But because these circuits carry only a part of the total path power flow, the resulting increase in pre-contingency capability could be up to 500 MW higher than the present limit. Such increases, for instance through real time rating of the transmission lines, could have major economic benefits.

Further increases are also possible. Any increase beyond the level studied in this project may require integrating real time rating data from the two other 230 kV circuits of Path 15 and real time rating data from associated substation equipment into the monitoring calculations. The limitations of the current project, and possible solutions, are discussed in this report.

Project Objectives

The overall goal of this project was the application of real time ratings technology to demonstrate the feasibility of implementing real time rating systems for Path 15, which is the most complex contingency-limited path in California.

The overall economic goal of this project was to prove the feasibility of real time ratings towards increasing the power transfer capability of Path 15, to achieve a potential savings of \$1 million per month during peak load periods of Path 15. The contractors believe that this goal has been met.

Project Approach

To implement real time ratings on Path 15, CAT-1 Transmission Line Monitoring Systems were installed at two sites on Gates-Panoche circuits 1 and 2, whose ratings are the primary limitations for post-contingency power transfer. Monitoring system data is transmitted from these sites to the CATMaster Base Station at Gates substation and further, via PG&E's standard SCADA protocol, to the Fresno area SCADA (Supervisory Control And Data Acquisition) system and to PG&E's control center in San Francisco. From this data, algorithms allow PG&E's

EMS (Energy Management System) to calculate the absolute conductor temperatures, temperature rises, and steady state ratings of the circuits. This data is then sent to the Path 15 rating computer.

Both the physical limitations of the lines and the system operating limitations were studied extensively. The major complication in the path ratings was the special Remedial Action Scheme (RAS), which is changed once every thirty seconds. Thus, ratings calculations must be performed after each resetting of the RAS, and must be compliant with the varying distribution factors for each element of the RAS.

The core of the real time rating program consists of the algorithms and the Path15DLR software which reside at PG&E's EMS center in San Francisco. The key components of the Path15DLR software are the Path15 Data Importer and PathLimit Calculator, which are designed to operate as two separate NT service applications. In addition to the line monitor data, which is sent pre-processed and error-checked from the PG&E's SCADA computer, the Path 15 rating computer receives the current RAS from the Path 15 RAS.

By early Spring 2002, all of the equipment had been installed and the programs had been tested and debugged. Since then, the system has been operational off-line and the data has been made available for PG&E's and CAISO's (California Independent System Operator) planning and operations personnel.

Project Outcomes

PG&E and CAISO have decided that because of the extreme importance of Path 15 reliability considerations, the real time ratings will only be used operationally after an extended offline experience. Additionally, CAISO wants to study a number of other higher contingency path limitations to determine what the new maximum contingency limitation of the path would be. Work is already under way, supported by a PIER grant, to develop real time rating methods on Gates transformer banks, which are an obvious higher level transfer limitation for Path 15.

One indication of the overall success of the project can be seen from the rapid deployment of real time rating systems on many other circuits in California. At present, there are 34 monitoring systems either installed or planned for immediate installation at five California utilities.

Conclusions

- The project has proven that real time ratings are a feasible method of improving the capability of Path 15, under the most critical operating conditions. Thus, real time ratings of Path 15 could result in significant energy cost savings.
- The CAT-1 Transmission Line Monitoring Systems used have been shown to be robust and stable during the two year period of operations.
- The DTRPath15 software has been shown to operate reliably over the extended period of trials. The calculated dynamic ratings have been shown to be reproducible by independent spot checks.

- The dynamic rating data indicates that the present assumed line ratings are generally conservative during the periods of highest loads on Path 15 (winter nighttime), but that they may not be conservative enough during summer daytime. On the other hand, high loads during summer daytime are extremely unlikely under present economic and supply conditions.
- The developed software is Path 15-specific. While the intellectual information gained from the application is significant, the software itself has no identified commercial potential at other identified locations

Benefits to California

- The potential benefits of the project to California depend on the acceptance of the developed software by CAISO. The total constraint cost of Path 15 amounts to tens of millions of dollars annually. Even limited use of the developed software could result in multi-million dollar annual savings.
- PG&E and CAISO are working to address the above additional limitations issues. It is also expected that, after a prolonged period of testing, the software developed in the project will result in actual real time operation.
- The technical success of the project has resulted in a number of additional real time rating applications in the PG&E system. Other California utilities are planning real time rating trials on a number of lines in 2003 and 2004.
- The project has resulted in the cleared definition of other potential limitations of Path 15. Some of these constraints are already being addressed.

Recommendations

- The required steps for full benefits from the project are development of application procedures, operational parallel testing, operator and dispatcher training and, possibly, increased redundancy of systems on the path. These steps should be undertaken by PG&E and CAISO.

1.0 Introduction

1.1. Background and Overview

California's Path 15 is the main transmission interface between northern and southern California. It is the most fundamental limitation for electric transactions within California under several different economic and seasonal conditions.

Path 15 is located at the southern part of PG&E's service area, near Fresno. It consists primarily of two 500 kV and four 230 kV circuits. Because the 500 kV lines share the same corridor, the path must be managed assuming a simultaneous forced outage of both 500 kV circuits. Thus, the thermal limitations of the 230 kV lines determine the transfer limits.

At present, the lines are thermally rated assuming a maximum (emergency) temperature of 100 °C, a 2 ft/sec crosswind, an ambient temperature adjusted in three steps, and a difference for day and night ratings. Under the most favorable conditions, this amounts to a maximum pre-contingency path capability of 3400 MW. In many cases, this capability is not sufficient, causing the path to become a key cause of congestion in California. Particularly during 2001, Path 15 caused frequent economical constraints. The cost of Path 15 constraints in the fourth quarter of 2001 was estimated to be at least \$60 million and possibly as high as \$300 million.

Thus, there is great interest in increasing the capability of Path 15, due to the large cost impact of the present constraints. For instance, a 10% useful rating increase of Pacific Gas & Electric's Gates-Panoche circuits of Path 15 amounts to a post-contingency increase of 45-55 MW per circuit. But because these circuits carry only a part of the total path power flow, the resulting increase in pre-contingency capability could be up to 500 MW higher than the present limit. Such increases, for instance through real time rating of the transmission lines, could have major economic benefits.

Further increases are also possible. Any increase beyond the level studied in this project may require integrating real time rating data from the two other 230 kV circuits of Path 15 and real time rating data from associated substation equipment into the monitoring calculations. These limitations of the current project, and possible solutions, are discussed later in the report.

1.2. Project Objectives

The overall goal of this project was the application of real time ratings technology to demonstrate the feasibility of implementing real time rating systems for Path 15, which is the most complex contingency-limited path in California.

The overall economic goal of this project was to prove the feasibility of real time ratings towards increasing the power transfer capability of Path 15, to achieve a potential savings of \$1 million per month during peak load periods of Path 15. The contractors believe that this goal has been met.

1.3. Report Organization

This report is organized as follows:

| | |
|-------------|--|
| Section 1.0 | Introduction |
| Section 2.0 | Project Approach |
| Section 3.0 | Project Outcomes |
| Section 4.0 | Path Management Software Development (Task 2.3) |
| Section 5.0 | Path Management Software Deployment (Task 2.4) |
| Section 6.0 | Feasibility Study on the Implementation of the Real Time Ratings Approach to Other California Paths (Task 2.5) |
| Section 7.0 | Conclusions and Recommendations |

There are 20 attachments:

| | |
|----------------|---|
| Attachment A1: | CAT-1 Brochure |
| Attachment A2: | CAT-1 Main Unit Specifications |
| Attachment A3: | Load Cell Specifications |
| Attachment A4: | CatMaster Specifications |
| Attachment B1: | Report to California Energy Commission and CAISO on Static Thermal Limitations |
| Attachment C1: | Initial Calibration Report |
| Attachment C2: | Final Calibration Report |
| Attachment D1: | Final Report on Physical Limitations |
| Attachment E1: | Final Report on Operating Limitations |
| Attachment F0: | Software Requirements Specification Report |
| Attachment F1: | Path15DLR10 Software Test Plan |
| Attachment F2: | Path15DLR 1.0 Test Script 01 |
| Attachment F3: | Path15DLR 1.0 Test Script 02 |
| Attachment F4: | Path15DLR 1.0 Test Script 03 |
| Attachment F5: | Path15DLR 1.0 Software Design Report |
| Attachment F6: | Path15DLR 1.0 Software Deployment- User's Guide |
| Attachment G1: | Presentation at T&D Conference- 2002 |
| Attachment G2: | Presentation at CAISO, June 2002 |
| Attachment G3: | Timo Seppa: "Alleviating Constraints on California's Path 15" |
| Attachment H1: | Feasibility Study on the Implementation of the Real Time Ratings Approach to other California Paths |
| Attachment H2: | Implementation of the real Time Ratings Approach to other California Paths. Supplement by Stanfield Systems, Inc. |

2.0 Project Approach

The contingency management of the path is very complex. When a 500 kV outage occurs, certain Remedial Action Schemes (RAS) are automatically activated. Certain loads are automatically tripped, including California Water System pumping loads north of the path, certain feeder loads, and generation at selected locations. Four minutes after the outage, each of the two Diablo Canyon nuclear units south of the path will start ramping down at a rate of 100 MW/minute for five minutes. The present planning calculations show that at the end of this ramping, the two most limiting 230 kV lines (Gates-Panoche), will reach a temperature of 100 °C, provided that the environmental assumptions of the rating calculations are valid.

In October 2000, PG&E installed four tension monitoring systems at the limiting 230 kV circuits. The data is presently received at PG&E's EMS center, where the EMS mainframe calculates steady state ratings. The initial installation was intended solely for proof-of-technology purposes, but it later provided an opportune platform for this CEC-funded project. In February 2001, CEC provided funding to for The Valley Group, Inc. (with key subcontractors Power Delivery Consultants, Inc. and Niskayuna Power Consultants) to develop the specialized software and revised procedures for more effective management of the path.

The project concept was to utilize the utility-owned tension monitoring systems to provide accurate information of the limiting circuits, combining this real time rating information with existing RAS scheme information, to calculate post-contingency conductor temperatures before contingency events. If the pre-contingency calculation indicates that post-contingency conductor temperatures are below the safety thresholds, the program solves the maximum allowable pre-contingency transfer limit by iteration. This real time path rating is displayed to system operators and allows a safe increase in the path transfer capability.

To implement real time ratings on Path 15, CAT-1 Transmission Line Monitoring Systems were installed at two sites on Gates-Panoche circuits 1 and 2, whose ratings are the primary limitations for post-contingency power transfer. Monitoring system data is transmitted from these sites to the CATMaster Base Station at Gates substation and further, via PG&E's standard SCADA protocol, to the Fresno area SCADA system and to PG&E's control center in San Francisco. From this data, algorithms allow PG&E's EMS system to calculate the absolute conductor temperatures, temperature rises, and steady state ratings of the circuits. This data is then sent to the Path 15 rating computer.

2.1. Transmission Line Monitoring Systems

The tension monitoring systems ("CAT-1 Transmission Line Monitoring Systems") used on Path 15 consist of solar-powered remote monitors ("CAT-1 monitors") placed at selected structures along the transmission line that communicate mechanical tensions and other measured data in real time via spread spectrum radios to a receiving unit ("CATMaster Base Station") at the substation, which then provides the information to PG&E's EMS/SCADA systems. At each remote location, located at a deadend structure, the conductor tension is monitored in two directions. A system calibration procedure determines the exact relationship between conductor temperature and tension for each location. After calibration, conductor temperature can be determined from measured tension at any given time. The real time rating calculation is based on comparing that conductor temperature to the Net Radiation Temperature (NRT) measured by each monitor.

Tension measurement allows direct monitoring for potential clearance violations along monitored line sections. Additionally, as accurate empirical verification of the line's sag/temperature relationship can be determined, with careful study, lines may be operated with reduced clearance margins compared to minimum statutory limits.

Wide empirical evidence from more than 250 monitoring sites has shown that the sags of a monitored line section can be determined with an accuracy of 10-15 cm even at distances more than 10 spans from the monitoring site. Consequently, the temperature rise of the monitored line section can be determined with an accuracy of ± 1.0 - 1.5°C . Thus, a reasonably accurate line rating can be derived for a current density even as low as 0.6–0.8 A/mm², which is about 20% of typical maximum allowed current density. For line currents below this level, the systems can revert to ratings calculated based on measured NRT and actual or assumed low wind speed.

Detailed information of the monitoring equipment is included in Attachments A1-A4.

3.0 Project Outcomes

3.1. Collection of Physical Information about Path 15 (Task 2.2)

The monitoring equipment was installed on the limiting Gates-Panoche circuits in October 2000, well ahead of the official beginning of the CEC project. This allowed data collection and evaluation of line rating conditions during different seasons over a period of two years, as well as verification of the reliability of the monitoring equipment and communications systems.

Operationally, the capability of Path 15 is typically most limited during winter months, when heavy South to North power transfers strain the limits of its transfer capability. The first important objective of the investigation of the collected data shows the following:

- During the winter, the capabilities of the Gates-Panoche circuits are generally high at nighttime and lower during the daytime. The nighttime capabilities are generally significantly higher than those assumed based on static ratings. This means that operationally, there appears to be substantial opportunities to exploit the dynamic ratings.
- During summer and early fall, the capabilities of the circuits are relatively low starting from noon, throughout the afternoon. Wind conditions are likely to be close to parallel to the line direction during the day. Conversely, nighttime capabilities are usually quite high, essentially always higher than the assumed planning ratings. Nighttime winds appear to be more perpendicular to the line.
- Data collected from the line is presented in Attachments B1 and C2.

The second important objective of historical data collection has been to verify the reliability of the monitoring equipment and the chosen data transmission method (spread spectrum radio) during extended operations. The results have been highly satisfactory.

Initial tests of the equipment and radio communications indicated data integrity of over 99.95%. Because the Path Software tolerates and accommodates error levels significantly below this performance, the reliability of monitoring equipment can be considered highly satisfactory. During later testing, there were a few periods of time when radio transmission conditions from the more distant site showed a weak radio signal. Yet, even these occasional error periods were considered not significant enough to justify moving the radio receiving site to an alternate location.

The tests identified a number of SCADA process related errors, which have been substantially rectified. These included improper SCADA deadbanding of temperature values. Recently, there have been SCADA data transmission errors, which have been caused by modification work done to the SCADA system. After the modifications are concluded, it is expected that performance will return to satisfactory.

The third major objective of the historical data collection was to verify the calibration stability of the equipment and the physical stability of the circuit itself (See Task 2.2.1 below). This was necessary because conductor property changes or structure movement could render the rating process inaccurate or necessitate frequent recalibrations.

The line was initially calibrated shortly after the installation of the equipment in December 2000. The calibration was checked in April 2001, resulting in minor adjustments. A final calibration was made in December 2002, using data from extended data collections during 2002. At that time, the algorithm coefficients used for calculating conductor temperature were modified to a higher order algorithm, to provide slightly increased accuracy at highest and lowest temperatures.

The December 2002 calibration indicated that there had been no drift in the monitoring equipment and that the conductor properties had not changed during the two year period of operation. Thus, for this line, the expected accuracy of the sag and tension measurements of the line is on the order of $\pm 0.25\%$, while the calculated conductor temperature accuracy is on the order of $\pm 1^\circ\text{C}$.

Calibration reports are included in Attachments C1 and C2.

3.1.1. Physical Limitations of the Gates-Panoche Transmission Lines (Task 2.2.1)

Under contingency conditions, the maximum allowable power flow through Path 15 depends on the thermal rating of the Gates-Panoche 230 kV line, since it must be capable of handling the power flows that result from the loss of the two 500 kV lines which run from Gates and Midway to Los Banos. Its thermal rating is based on clearance limitations and is subject to the accuracy of the assumed thermal model. These limitations were investigated in Task 2.2.1.

As a complement to the dynamic thermal rating of the Gates-Panoche line, the physical condition of the line was studied and various more conventional techniques for increasing the line rating were evaluated. Given the limited amount of detailed field data available, the report gives tentative conclusions and recommendations which will require more study if they are to be implemented to further improve the path capability.

The following are the tentative conclusions of the report:

1. The present thermal rating calculation methods used by PG&E are consistent with the best industry practice and reflect prudent assumed rating conditions.
2. Data obtained from the installation of the CAT-1 monitors near Panoche indicate that the sag-tension state of the line is quite similar to the design conditions.
3. There is little clearance margin in the present line when it is operated at 100°C . Thus, it does not appear possible to operate the line at temperatures above 100°C without physical modification.
4. The field data upon which the CAT-1 Net Radiation Sensors (NRS) are calibrated indicate that the conductor is somewhat darker than is assumed in present thermal rating calculations. If adjusted for the correspondingly increased emissivity, the line rating would be about 4% higher than at present. This rating increase would require no physical modification of the line or any loss of service.
5. The line can probably be retensioned without significant structure modifications to increase the rating by approximately 8%. If the angle and deadend structures of the line were reinforced or replaced, retensioning the line might yield a rating increase of as much as 20%. Any attempt to retension the line would require an extensive line outage and an equally extensive derating of Path 15 during the work. Since the "Condor" conductor would not to

be replaced during this retensioning work, the cost of this upgrade would be less than for normal reconductoring.

6. If the line's Condor ACSR (Aluminum Core, Steel Reinforced) conductor were replaced with Condor/ ACSS (Aluminum Core, Steel Supported) or Columbia/ ACSS/TW (Aluminum Core, Steel Supported/Trapezoidal Wire), the line rating could be increased by 49% or 59%, respectively. No reinforcement would be required to deadend and angle structures for the Condor/ ACSS, but such reinforcement would probably be required for the larger Columbia/ ACSS/TW conductor. Reconductoring with either conductor would require an extended outage and period of reduced Path 15 capability. The total cost would likely be about half the cost of a new 230 kV line, exclusive of right-of-way costs.

All of the methods of uprating, which depend on physical modification of the line, are complementary to the CAT-1 monitor-based dynamic thermal rating technology which is now installed on the lines.

The more expensive methods of physical uprating, such as reconductoring with ACSS, are unlikely to generate significantly higher Path 15 transfer limits since these limits depend upon the rating of other path elements as well as on the rating of the Gates-Panoche line.

A complete report on Physical Limitations is in Attachment D1.

3.1.2. Examination of Path Operating Limitations (Task 2.2.2)

The operating limitations of Path 15 are extremely complex. They depend on the physical limitations of the path itself, on voltage and other constraints in other California interfaces, power transmission along other WECC paths, and distribution of loads and generation in California and elsewhere in WECC. These limitations were studied in depth, with two major objectives:

1. To develop an understanding of relevant system characteristics and the existing path rating procedures.
2. To identify opportunities for improvement in the path rating procedures that can be addressed by the proposed real time rating system.

Consequently, this report focuses on the path limitations that are caused by thermal overloads of transmission lines. System characteristics as well as the existing rating procedures are described in detail in several CAISO [1,2,8,9] and PG&E [3,4,5,6,7] documents.

3.2. Present Operational Methods

Operating Procedure T-122 defines Path 15 ratings as observed by CAISO in day-to-day operation. Base ratings are differentiated by three ambient temperature categories and by the amount of RAS action armed at any given time. In addition, ratings can be increased by 300 MW for certain restricted operating conditions. Operating aspects limiting the Path 15 ratings include voltage limits and reactive reserve requirements, overloading of series capacitors on the Gates to Los Banos 500 kV line and overload on the Gates 500/230 kV transformer and the Gates-Panoche 230 kV lines during the Double Line Outage (DLO) contingency. In addition,

the flows on Path 15 must be coordinated with the West of Borah path because of voltage-restricted transfers on this path.

The objective was limited to the analysis of system and control characteristics that are relevant for the determination of the maximum power that can be transferred across Path 15 considering the loading of the Gates-Panoche line for the DLO contingency. This limit (P15-DLO-GP rating) can be determined by the proposed Real Time Rating System (RTRS) in real time separately and independent of the other potentially limiting conditions. This offers several enhancements over the present procedure:

- The present procedure recognizes three categories of ambient temperature and daytime/nighttime combinations. In contrast, the RTRS rating will reflect actual ambient conditions as determined continuously by the CAT-1 monitoring system and associated software. That is, the ratings are continuously updated according to actual ambient temperature, solar insolation, and effective wind speed.
- Presently, two categories of system conditions (load and generation patterns) are recognized. In contrast, the RTRS rating reflects actual load and generation patterns in real time via telemetered values of the MW flow on the two 500 kV lines on Path 15 and the Gates-Panoche 230 kV line. Given a specific system configuration, these three telemetered values include all intelligence required to continuously update the P15-DLO-GP rating according to changing load and generation dispatch.
- The present procedure handles the impact of maintenance outages as specific MW deratings to the normal Path 15 ratings. In contrast, the RTRS system produces the P15-DLO-GT rating in the same way as for the normal condition, except that a different system model, consisting of a set of precomputed distribution factors, is applied.
- The present procedure takes advantage of the short-term thermal overload capability of transmission lines by relying on the rapid ramp-down of Diablo Canyon during the first 9 minutes after the occurrence of the DLO and a corresponding ramp-up in generation north of Path 15 in the same time frame. The benefit of these operating actions is determined by off-line studies. The RTRS will utilize the same concept except that the calculations will be performed on the fly every 30 seconds. Thus, the P15-DLO-GP can reflect changes in generation response capabilities that may restrict the effectiveness of operating procedures. While not included in the initial implementation of the RTRS, the process can be expanded to handle the specification of additional remedial operator actions. Changes in critical parameters such as the maximum of generation adjustment available at a specific location in the required time frame can be updated in real time.

3.3. System Structure around Path 15

Figure 1 shows the structure of the transmission system around Path 15. The path, which is a transmission bottleneck for power flowing from south to north in PG&E's service territory, consists of the following parallel transmission lines:

1. Gates-Los Banos 500 kV line.
2. Midway-Los Banos 500 kV line.

3. Gates-Panoche 230 kV double circuit line. This double circuit line consists of two identical circuits on a common tower.
4. Gates-Gregg 230 kV line (More precisely, the Henrietta¹ to Gregg segment of this line).
5. Gates-McCall 230 kV line (More precisely, the Henrietta to McCall segment of this line).

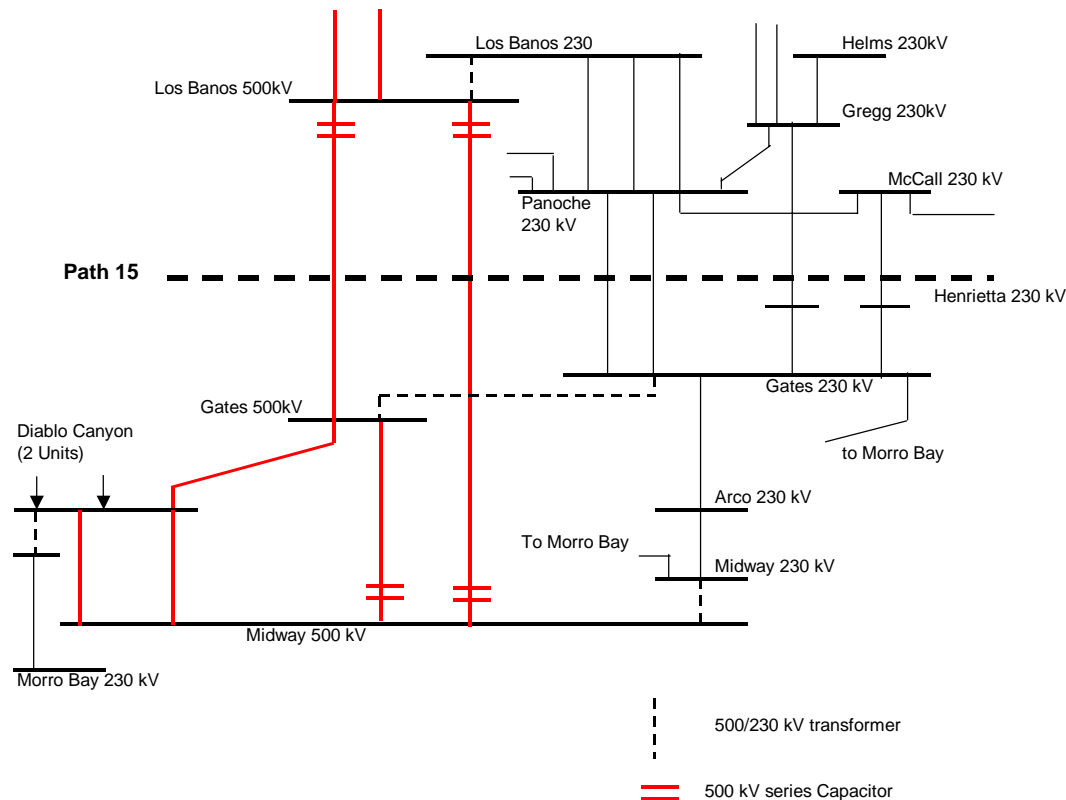


Figure 1. Structure of Transmission System around Path 15

3.4. The Nature of Limiting Conditions on Path 15

Path 15 may be limited with all lines in (N-0), for single contingencies (N-1) and for the simultaneous loss of the two 500 kV lines on Path 15 (N-2 contingency). The following is a summary of information received from PG&E.

¹ Both the Gates-Gregg line and the Gates-McCall line have an intermediate tap point at Henrietta. However, there is no connection between the two lines at the two tap points. The Henrietta tap on the Gates-Gregg line has some significance in that there is a small amount of load on this tap. There is presently no load at the Henrietta tap point on the Gates-McCall line.

N-0

Path 15 may be limited by the 1800 amp normal rating of the series capacitors on either the Los Banos-Midway 500 kV line or the Los Banos-Gates 500 kV line

N-1

Path 15 may be limited by the short-term emergency rating (2700 amps) of the series capacitors on the Los Banos-Midway 500 kV line for loss of the Los Banos-Gates 500 kV line. Criteria for N-1 conditions require that the loading of equipment will not exceed an emergency rating for a time duration that is sufficient to allow time for operators to detect, diagnose, and end relieve the overload problem through generation redispatch or other ordinary operator actions. The short-term series capacitor emergency rating has a 30 minute maximum time duration.

N-2

Path 15 may be limited by thermal limitations resulting from the simultaneous outage of the two 500 kV lines on Path 15. This outage is referred to as the Los Banos South Double Line Outage or "LBS DLO". In this report, the outage will be referred to simply as DLO. The limiting facility for DLO is either the Gates-Panoche 230 kV circuits or the Midway 500/230 kV transformer. In either case, limits are defined based on dynamic ratings in which advantage is taken of the short-term overload capability of lines or transformers.

A sophisticated Remedial Action Scheme (RAS) has been implemented to detect the DLO contingency and to immediately and automatically shed load north of Path 15 and trip generation south of Path 15. These automatic actions will reduce the post contingency loading on the Gates-Panoche 230 kV lines. Since the path rating is limited by the post contingency loading of these circuits, RAS allows operation at a higher flow across Path 15 than would otherwise be possible. A further increase in the path rating is obtained by a manual operating procedure that calls for ramping down the Diablo Canyon units as rapidly as possible after DLO contingency. In addition, the system operator can order additional load reduction north of Path 15 and additional generation reduction south of Path 15. These additional manual actions are not considered when determining the rating of Path 15, but provide a margin of safety if needed during an actual emergency.

DLO may also cause voltage problems in the Panoche area. Adequate control of voltage problems are assured through automatic insertion of shunt capacitors immediately north of Path 15. The limiting condition of interest in this project is the thermal limitation associated with the Gates-Panoche line. Voltage limitations are not considered

The above summary is valid for the normal system conditions when all essential 500 kV and 230 kV transmission equipment is in service prior to the contingency. PG&E also identified a number of maintenance outages where conditions other than those listed above may be limiting. With regard to thermal line overloads, these maintenance outages may reduce the Path 15 rating either because the initial power flow on the facility immediately after a contingency is impacted or because the availability of remedial actions relied upon when establishing the path rating is unavailable or their effectiveness reduced.

3.4.1. Interaction with West of Borah Path Limits

With all circuits in service, an increase in power generation in the Los Angeles area, matched by a decrease in power generation in Oregon/Washington, distributes in the following fashion, as illustrated in Figure 2²:

1. From north to south across Path 15: 77.4%.
2. On eastern path of WECC system, via Arizona-Nevada-Utah-Colorado-Idaho: About 20.7%.
3. On lower voltage systems in California: About 1.9%.

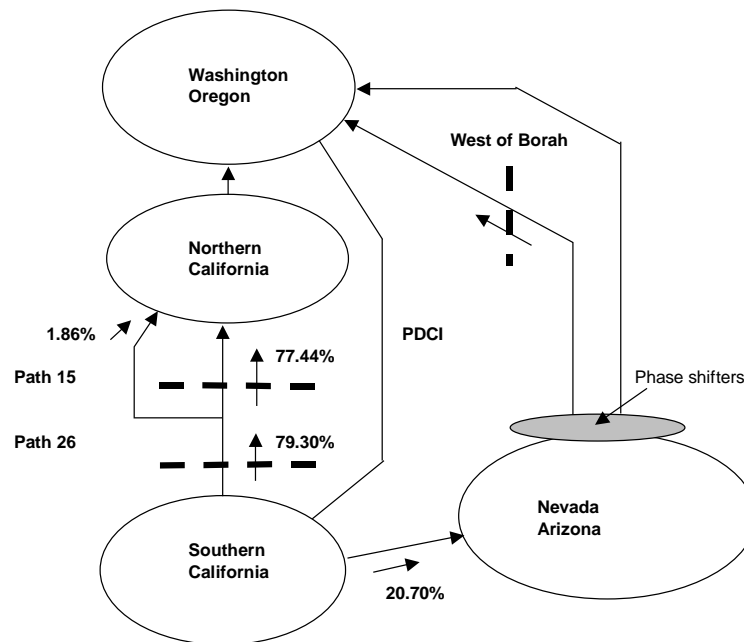


Figure 2. Distribution of an incremental increase in power transfer from Southern California to Washington/Oregon

While the numbers vary to some degree, the situation is qualitatively the same for power transfers from any point south of Path 15 to any point north of Path 15.

A portion of the flow on the eastern path of the WECC system flows across the West of Borah path in Idaho. Under certain load and generation dispatch conditions, the amount of power that can be transferred from Southern California to Northern California is limited by the West of Borah path rating rather than the maximum Path 15 rating. This relationship is defined in a “nomogram” of the type illustrated in Figure 3. If the flow on the West of Borah path is

² The flow distribution shown was obtained by distribution factor analysis on the 2001 winter light load flow case submitted by PG&E for use in this project.

pushing against its limit, the flow across Path 15 may have to be reduced to a value that is lower than the limit defined by system conditions at and in the immediate vicinity of Path 15. The interaction is expressed by the sloped line for the higher values of West of Borah flows. While this is an integral and very important aspect of the management of Path 15 flows, the problem is separable from the problem of determining the thermal limits of Path 15. The real time rating system will impact the level of the horizontal line in Figure 3. This level is independent of the flows on the West of Borah path.

The West of Borah limitation is caused by a low voltage problem. In order to maintain the limit as shown in Figure 3, shunt capacitors may be switched in during heavy loading across the West of Borah path.

When power is transferred from Southern California to Northern California or to Oregon/Washington, the division of flow between Path 15 and the eastern path of the WECC system can be controlled by adjusting the setting of phase shifters located on the interface between the Arizona and Utah transmission systems. Adjusting the phase shifters such that the operating point becomes the corner point in Figure 3 maximizes the south to north transfer. The corner point is the point where the sloped line crosses the horizontal Path 15 limit line.

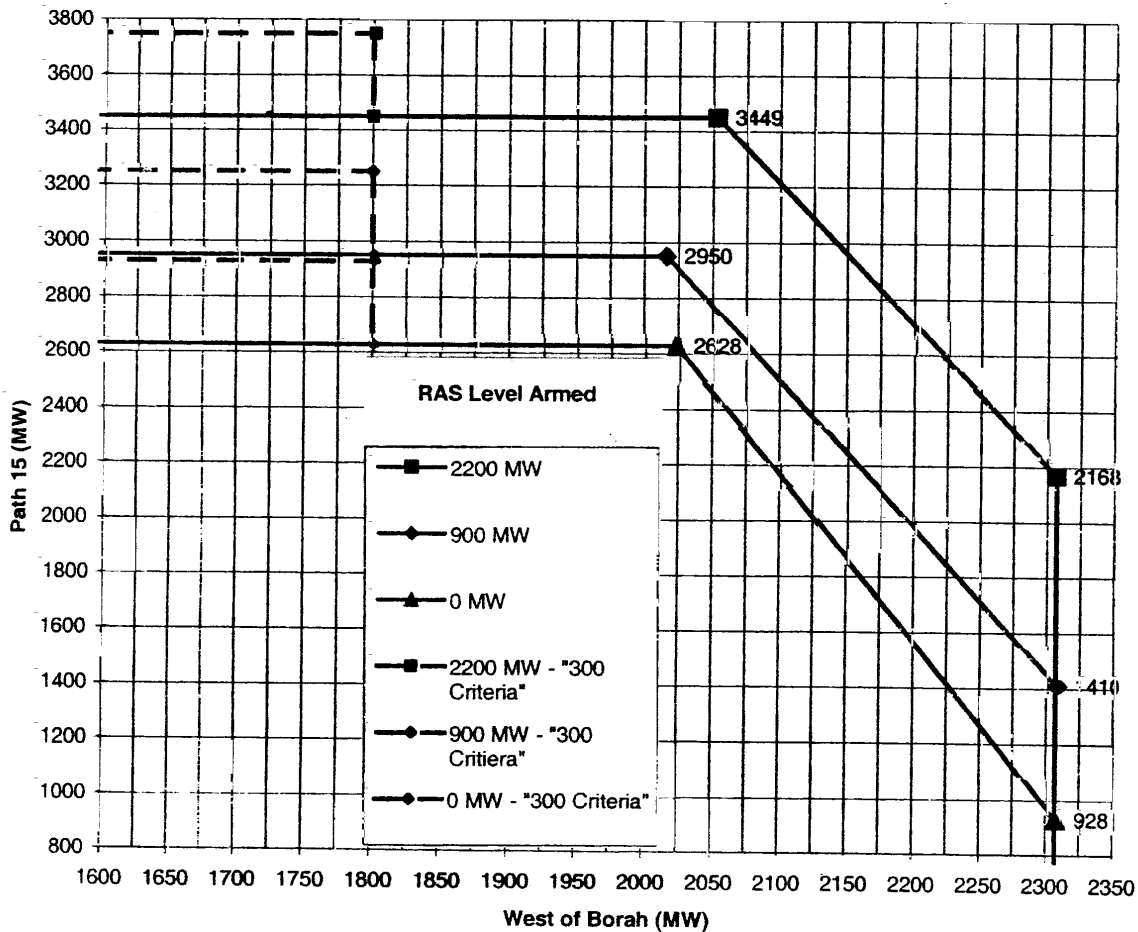


Figure 3. West of Borah Versus Path 15 Nomogram for Temperatures <62°F (Daytime) and < 71°F (Nighttime)

The horizontal lines in Figure 3 represent thermal limitations on Path 15. The Gates-Panoche line is limited for DLO for RAS = 900 MW (P15 rating=2950 MW) and 2200 MW (P15 rating = 3449 MW). The 500/230 kV transformer at Gates is the limiting element for RAS = 0 (P15 rating = 2628 MW), also for DLO conditions. For certain favorable system conditions, including restrictions on generation at Helms, these ratings are increased by 300 MW. Thus, if the favorable conditions are met and with RAS at 2200 MW, the Path 15 rating caused by the Gates-Panoche DLO limitation is 3750 MW. This rating is only allowed for West of Borah path flow at less than 1800 MW.

3.4.2. The Pacific DC Intertie

If the flow on the Pacific DC Intertie (PDCI as indicated in Figure 2) is in a northerly direction, an increase in this flow will result in reduced flow on Path 15. Similarly, if the flow is in a southerly direction, a reduction in this flow or a reversal of flow will reduce the flow on Path 15.

This is recognized as a potential remedial action [1], but is not relied upon when establishing path ratings. From a system structure standpoint, control of the PDCI flow would form an attractive remedial action for increasing Path 15 ratings. There may, however be both technical and institutional reasons for not relying on the PDCI at this time. If the reasons are primarily technical (control, communication, and short term overload capability), there may be reasons to revisit this issue when the existing mercury arc valves are replaced by modern solid-state converters.

3.4.3. Summary of Limiting Conditions

The Path 15 rating is generally³ limited by one of the following conditions (See also:

Section 3.6):

1. Normal series capacitor ratings on the 500 kV lines (N-0).
2. Short term emergency ratings of the series capacitors on the Los Banos-Midway 500 kV line for loss of the Los Banos-Gates 500 kV line (N-1).
3. Voltage conditions at Panoche caused by the DLO (N-2).
4. Thermal overloads on the 500/230 kV transformer at Gates caused by the DLO (N-2).
5. Thermal overloads on the Gates-Panoche lines caused by the DLO (N-2).

Limits can be determined separately for each item. The Path 15 rating is the lowest value of the limits determined. In addition, the flow on Path 15 may have to be restricted when the associated flow across the West of Borah path becomes limited because of low voltage conditions in Idaho. This project deals with the determination of condition 5 above, the Path 15 limit caused by the loading of the Gates-Panoche line for the DLO contingency condition. This limit will be referred to as the P15-DLO-GP rating in this report. It can be determined separately and independently of the other limits. P15-DLO-GP will become the Path 15 rating if it is the most restrictive of the 5 conditions listed above. The integration of the various limiting conditions and the display of this information to operators is not considered in this project.

3.5. Existing Rating Scheme for Thermal Limitations on Path 15

3.5.1. Common Rating Practices – Static Ratings

Common utility practice limits the utilization of a transmission system to levels where single contingencies (e.g. loss of a single line or transformer) do not result in the electric current on any transmission facility exceeding its emergency rating. The emergency rating is defined as a loading level that can be tolerated for a limited time period. This time period is sufficiently long to allow the operators to lower the current to within the normal (continuous) rating by means of

³ Other limiting conditions may apply during maintenance outages of transmission equipment, if facilities included in the RAS should be unavailable, or if the Diablo Canyon units are not operating.

ordinary operator actions. Generally, automatic remedial actions are not relied upon to reduce the post-contingency line currents. The emergency current ratings of transmission lines are typically defined by the maximum conductor temperature allowed for single contingencies. In the PG&E service territory, this maximum temperature is 80 °C. The post contingency line current that will bring the conductor temperature up to 80 °C depends on environmental factors such as the ambient temperature, wind speed and solar heating of the conductor.

When determining thermal limits on Path 15 based on the DLO contingency, PG&E has defined three temperature ranges with separate line and path ratings. This will result in ratings that may vary from one day to the next and between daytime and nighttime hours. The changes from one rating to another are still abrupt, but the method represents a significant refinement over common utility practice. This scheme is discussed in detail later in this section.

Use of a RTRS such as the CAT-1 system will dispense with static summer and winter ratings in favor of a continuously varying rating which responds to changing environmental conditions. Thus, the CAT-1 RTRS will allow maximum utilization of the thermal capacity of the transmission system at all times. Further, the risk of inadvertently and unknowingly exceeding criterion conductor temperature will be reduced.

3.6. Existing Procedure for Determining Path 15 Ratings Based on Thermal Loading of the Gates-Panoche 230 kV Line for the DLO

3.6.1. The Basic Rating Scheme

The present rating procedure has the following ingredients:

1. RAS action is initiated automatically within a fraction of a second after the occurrence of DLO.
2. The output of the Diablo Canyon Power plant is reduced to half power within 9 minutes.
3. Advantage is taken of the thermal inertia of transmission line conductors. This allows time for reducing the line current by backing off the Diablo Canyon plant before the current has reached its maximum value.
4. A 100 °C maximum conductor temperature is allowed.
5. Three different line current ratings are used, corresponding to specified night and day temperatures.
6. Ratings are subject to adjustment by ISO personnel in response to changes in system conditions.

3.6.2. Special Line Ratings Determined Based on Rapid Ramp-Down of Diablo Canyon within 9 Minutes of the DLO Contingency

The special rating procedure for the Gates-Panoche line for the DLO contingency is based on ensuring that under expected ambient temperatures and operating procedures, the conductor temperature does not exceed 100 °C⁴. The line ratings are determined based on the loading diagram shown in Figure 4.⁵ This diagram is a timeline of the Gates-Panoche 230 kV line loading and conductor temperature. The Gates-Panoche 230 kV lines begin with some pre-outage loading and conductor temperature as shown for time $t < 0$. Following the DLO, the Gates-Panoche 230 kV line loading increases to some peak value and the conductor temperature begins to increase. The impact of the automatic RAS actions are not indicated in Figure 4, but will be discussed later.

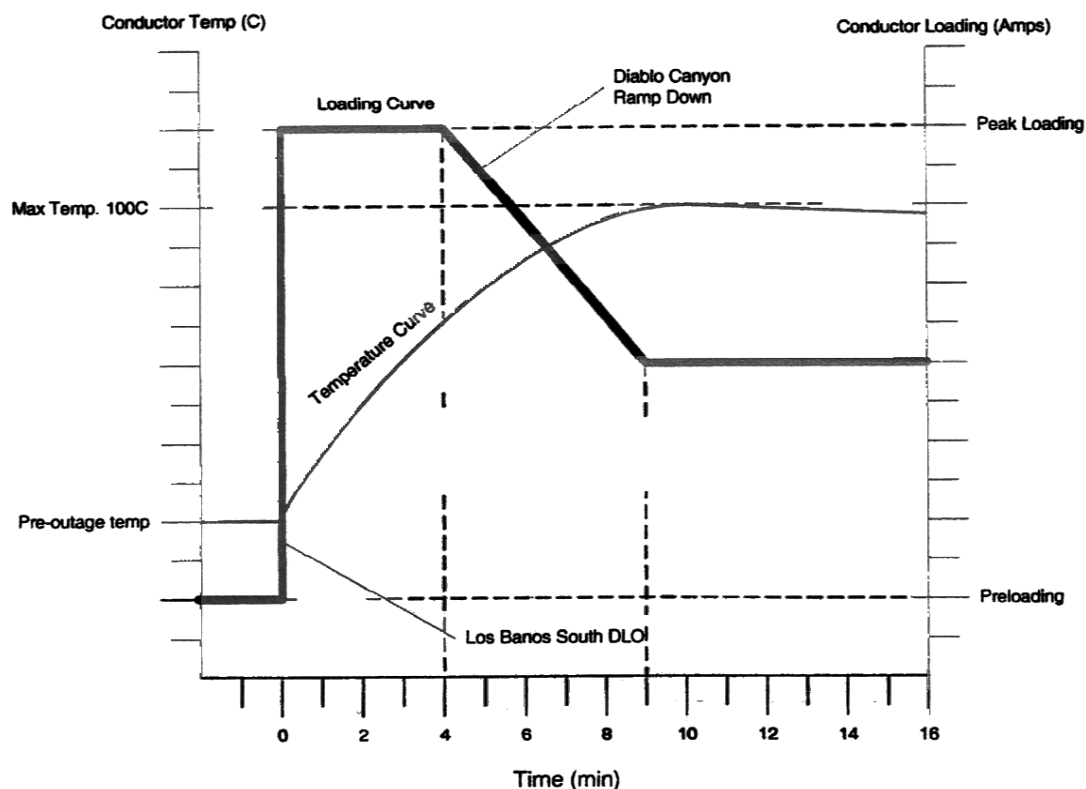


Figure 4. Time functions of Conductor Current and Conductor Temperature on the Gates-Panoche 230 kV lines.^a

a) The special current rating calculated is the “Peak loading” that results in a maximum conductor temperature of 100°C

⁴ PG&E describes the 100 °C maximum allowable conductor temperature as a special limit allowed only “after a complete assessment of the condition of the line. The temperature limit is restricted to no more than 30 hours during the life of the conductor”.

⁵ This diagram and the following description is an adaptation of a rating procedure description received from PG&E.

Within 4 minutes, operating procedures are implemented to begin ramping down Diablo Canyon Power Plant at 100 MW/min/unit for 5 minutes. This reduces the loading on the Gates-Panoche 230 kV lines, which in turn slows the heating of the conductors. After 9 minutes, the loading on the Gates-Panoche 230 kV lines has stabilized at some level lower than the peak. Also, the conductor temperature reaches a maximum value and begins to decrease.

The rating process determines the initial post contingency loading (for the first 4 minutes) on the Gates-Panoche lines which will result in a maximum conductor temperature of 100 °C, given a specific pre-contingency loading for the lines, ambient temperature, and the expected reduction in line loading caused by the ramp-down of the Diablo Canyon plant. The pre-contingency loading is assumed to be 525 amps. The reduction in line loading caused by the ramp-down of the Diablo Canyon plant is assumed to be 600 amps. This is based on results of PG&E system studies, which show that ramping Diablo Canyon Power Plant down by 1000 MW (100 MW/min/unit for 5 minutes) results in a reduction of the Gates-Panoche 230 kV line flows of 600 to 650 amps⁶.

Three ratings have been determined using this procedure, each valid for a specified range of daytime ambient temperatures and a corresponding range of nighttime temperatures. See Table 1. The difference in daytime and nighttime temperature ranges is caused by the impact of solar heating during daytime conditions. Wind speeds are assumed to be at 2 ft/sec in either case.

Ratings depend on the availability of ramp-down of Diablo Canyon units by 1000 MW within the first 9 minutes of DLO and a pre-contingency loading of the Gates-Panoche lines not exceeding 525 amp.

| Rating (Amps) | Day-time temperature range | Night-time temperature range |
|---------------|---|---|
| 1800 | $\leq 62\text{ }^{\circ}\text{F}$ | $\leq 71\text{ }^{\circ}\text{F}$ |
| 1570 | $62\text{ }^{\circ}\text{F} < T \leq 90\text{ }^{\circ}\text{F}$ | $71\text{ }^{\circ}\text{F} < T \leq 105\text{ }^{\circ}\text{F}$ |
| 1300 | $90\text{ }^{\circ}\text{F} < T \leq 120\text{ }^{\circ}\text{F}$ | $105\text{ }^{\circ}\text{F} < T < 135\text{ }^{\circ}\text{F}$ |

Table 1. Special line ratings for Gates-Panoche lines valid for the DLO contingency.

3.7. Translation of Special Gates-Panoche Line Ratings into Path 15 Limits

PG&E has translated the special ratings for the Gates-Panoche 230 kV line into Path 15 thermal limits based on power system studies covering a variety of system conditions. The results of

⁶ Simultaneous increase in generation north of Path 15 is also assumed. See Section 3.8.

these studies, including the actual Path 15 ratings used, have been analyzed and compared to the results obtainable from the methodology proposed for the RTRS in Section 3.8.

Assuming no RAS action applied, the three special ratings in Table 1 result in three ratings for Path 15. In addition, there is a second rating that is 300 MW higher, that can be applied to a more restricted set of system conditions, that results in a lower DLO loading of the Gates-Panoche line than can be generally assumed. Thus, assuming no RAS action, the existing rating procedure produces a total of six P15-DLO-GP ratings as a function of environmental conditions and pre-contingency power system conditions.

3.8. Outline of the Path 15 Rating Methodology Proposed for the Real Time Rating System

This section contains a brief description of the Path 15 Dynamic Line Rating (Path15DLR) software, the computer application in the RTRS that calculates the P15-DLO-GP rating based on input from CAT-1, SCADA, and the RAS controller. This overview is provided to allow a comparison of the RTRS with the present procedures and to identify aspects of the rating process where improvements can be made.

The Path15DLR software calculates ratings limited by the line loading of Gates-Panoche 230 kV lines after the simultaneous loss of the two 500 kV lines on Path 15 (the DLO contingency). This rating may change in response to one or more of the following events:

1. Change in environmental conditions impacting the line current/conductor temperature relationship. Such changes may be updated at a frequency of about 3 to 6 times per hour.
2. Change in RAS arming or significant change in the amount of power available to be tripped for each RAS action. Ratings will be calculated immediately after data is received from the RAS controller. The frequency of new RAS input to the Path15DLR system is once every 30 seconds.
3. Change in telemetered flows from one or more of the following three lines: Gates-Los Banos 500 kV line, Midway-Los Banos 500 kV line, and Gates-Panoche 230 kV line.
4. Significant change in system configuration that will result in the use of a different set of system model constants (distribution factors). These are changes that cause a significant change in the distribution of power among the 230 kV lines emanating from Gates towards the north. This information will be submitted to the Path15DLR from the RAS controller.

These ratings will be calculated and made available by the Path15DLR as calculated for two conditions:

1. Assuming RAS action as currently armed.
2. Assuming that all available RAS actions will be armed.

New limits would be available from the Path15DLR whenever the calculated ratings change by a specified threshold amount. The integration of the DLO thermal rating information with the other potentially limiting conditions for Path 15 will not be addressed in this project. A

simplified flow chart of the Path15DLR is displayed in Figure 5. A brief description of the major items follows:

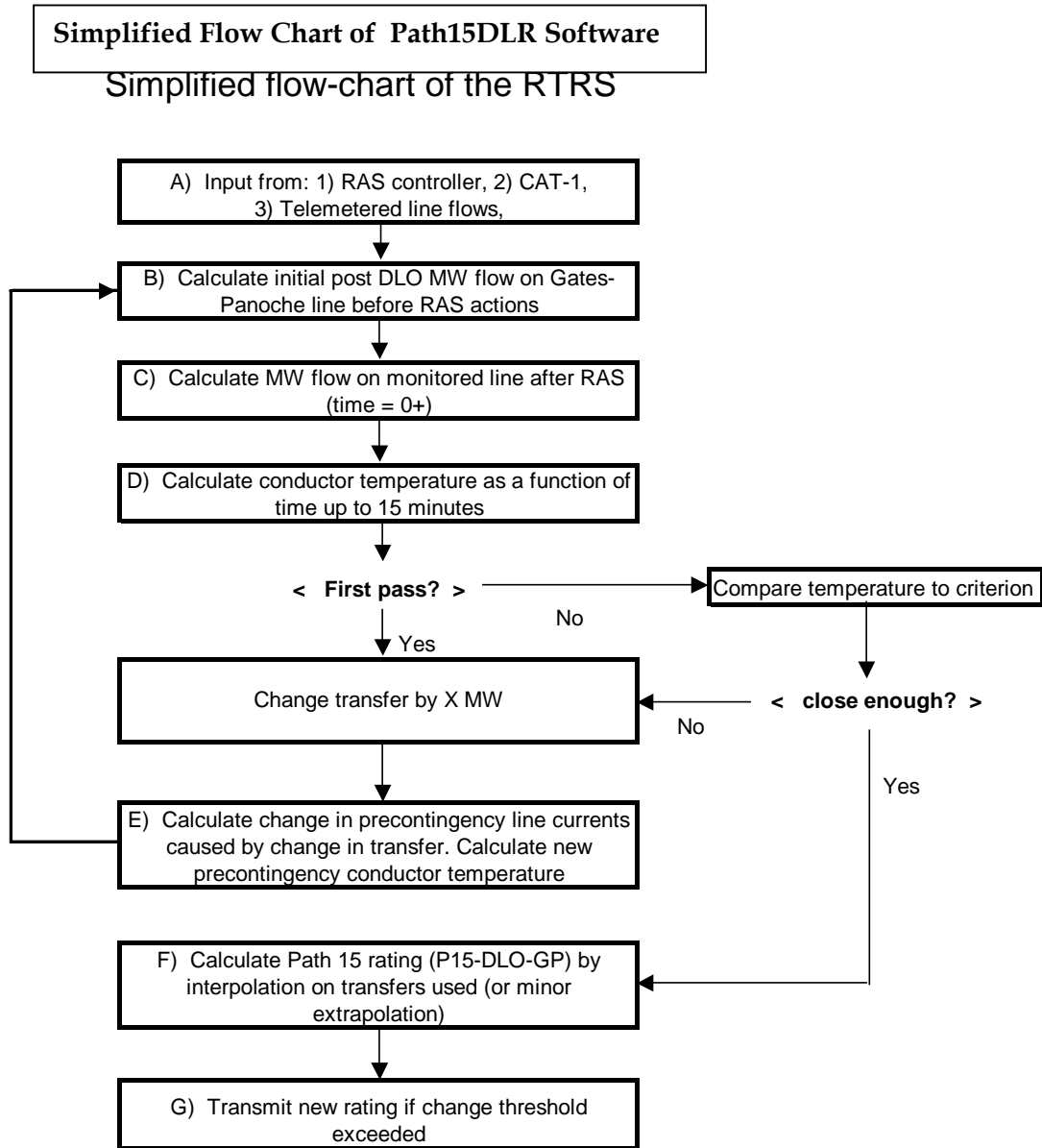


Figure 5. Simplified flow chart of the Path15DLR software^a

a) P15-DLO-GP ratings reflecting any change in critical line flows, environmental conditions or RAS arming are updated every 30 seconds

Block A: The real time current rating of the conductors on the Gates-Panoche line is updated periodically by the CAT-1 real time rating software based on measurements from the CAT-1 installations and actual telemetered current flows on the line. Information about available and armed RAS action is received from the RAS controller. In addition, telemetered line flows for the two 500 kV lines on Path 15 and the Gates-Panoche lines are received from the SCADA system.

Block B: The post DLO MW flow on each of the Gates-Panoche lines is calculated as follows:

$$PC_{\text{post}} = PC + k_A * PA + k_B * PB$$

Where:

PA = pre-contingency MW flow on the Gates-Los Banos 500 kV line

PB = pre-contingency MW flow on the Midway-Los Banos 500 kV line

PC = pre-contingency MW flow on one of the Gates-Panoche 230 kV lines.

k_A and k_B are constants (distribution factors) valid for a particular pre-contingency system configuration.

The k -values vary only with changes in system impedances and system structure. They do not change appreciably with generation dispatch or load. Events that would result in a change in k -values would include the outage of a line in the neighborhood of Path 15 that would change the flow distribution on the 230 kV lines emanating northward from Gates. Also a major change in impedance in the "Big Loop" (California-Arizona-Nevada-Idaho-Oregon) may have an impact on the k -values.

Thus, the post contingency flow on the Gates-Panoche 230 kV line is readily calculated from present pre-contingency MW values available in the SCADA system. Similarly, post-contingency flow values can be calculated for a future condition based on predicted MW flow values on A, B, and C. Such predictions are obtainable from a load flow solution of forecast future conditions – or they can be calculated based on a handful of precomputed distribution factors.

Block C: The impact of RAS action is to automatically and immediately (within a fraction of a second) reduce the Gates-Panoche line flow to a lower value. The resulting post-RAS line flow is determined based on the amount of RAS action that can be activated and the effectiveness of each RAS action in reducing the line flow.

Block D: Starting with the reduced post-RAS current flow on the Gates-Panoche line, a current vs. time curve that includes the effect of the Diablo Canyon ramp-down can be constructed and the corresponding temperature function calculated (See Figure 4).

During the initial pass, the temperature function represents present transfer conditions. If the maximum temperature is less than the criterion 100 °C, then the Path 15 thermal rating for the DLO Gates-Panoche line limitation is greater than the present Path 15 flow. By defining a somewhat higher transfer condition and recalculating the temperature function for this higher transfer, a new maximum temperature is found that can be compared to the 100 °C, criterion. After a few iterations and appropriate interpolation or extrapolation, the transfer that yields a

maximum temperature of precisely 100 °C is determined. This is the P15-DLO-GP rating, the P15 thermal rating for the DLO Gates-Panoche limitation.

A new P15-DLO-GP rating is produced every 30 seconds, immediately after receipt of new data from the RAS controller. This rating may be transmitted immediately to the PG&E and CAISO operating computers or rating updates may be transmitted only after the calculated rating has increased or decreased by a specified threshold value above or below the previously transmitted value.

The data for maximum available RAS as represented in the Winter 2001 light load flow case are summarized in Table 2. Note that the total RAS MW matches the maximum of 2200 MW shown in Figure 3, required to obtain the 3750 MW P15-DLO-GP rating for that case. The post-DLO loading relief on the Gates-Panoche line caused by the 2200 MW RAS action is 227 MW. The corresponding increase in the P15-DLO-GP rating is 960 MW. On average, each MW of RAS action yields an increase in the P15 rating of 0.439 MW. This value is subject to the system response uncertainties discussed earlier, but only to the extent that RAS tripping of pumping load and general load is not compensated for by RAS tripping of generation.

Summary of calculated Effectiveness Factors of RAS actions based on 2001 winter light load flow case and the inertial redispatch assumption

| | Generators | Pumps | Loads | Total |
|--|------------|-------|-------|-------|
| MW available for Tripping in 2001 summer load flow case | 513 | 632 | 1042 | 2187 |
| Impact on Gates -Panoche line loading (MW) | -63 | -68 | -96 | -227 |
| Impact on South-North transfer | 342 | 372 | 527 | 1240 |
| Impact on P15-DLO-GP rating | 265 | 288 | 408 | 960 |
| Effectiveness: Change in P15-DLO-GP rating / MW tripped | 0.517 | 0.455 | 0.391 | 0.439 |
| Conservative Effectiveness assumed by PG&E | 0.510 | 0.370 | 0.350 | 0.390 |

Table 2.

PG&E stated in a May 8, 2001 conference call that present P15-DLO-GP ratings are based on a conservative interpretation of their study results that includes an inertial redispatch assumption similar to the one used in this project. The average conservative values for generation, pumps, and loads are listed at the bottom of Table 2. The 0.37 value for pumping units does not include the Helms units which have an effectiveness factor of 0.35. Applying these effectiveness factors to the available RAS in the 2001 winter light case yields an average effectiveness factor RAS action of 0.39.

The PG&E values are not necessarily directly comparable to the results obtained in this project, which are based on the specific set of available RAS actions available for the Winter 2001 light load flow case. However, the results are compatible, and the values applied by PG&E are conservative compared to those obtained based on the inertial dispatch assumption and the 2001 load flow case system and generation configuration.

The PG&E RAS system does not control each individual RAS action listed in Appendix A. Rather the actions are activated in groups [4,5]. Further, the arming of RAS actions is subject to a random selection process. This is done to avoid a systematic high exposure to interruption of some RAS actions relative to others. In theory, this might introduce a degree of uncertainty into the impact of the RAS actions and the possible arming of a greater amount of RAS actions than necessary. This project has not attempted to quantify these impacts. However, considering the relatively narrow spread in effectiveness factors for the RAS actions, the impact of the random selection process does not appear to be significant.

The complete report on Operating Limitations is in Attachment E1.

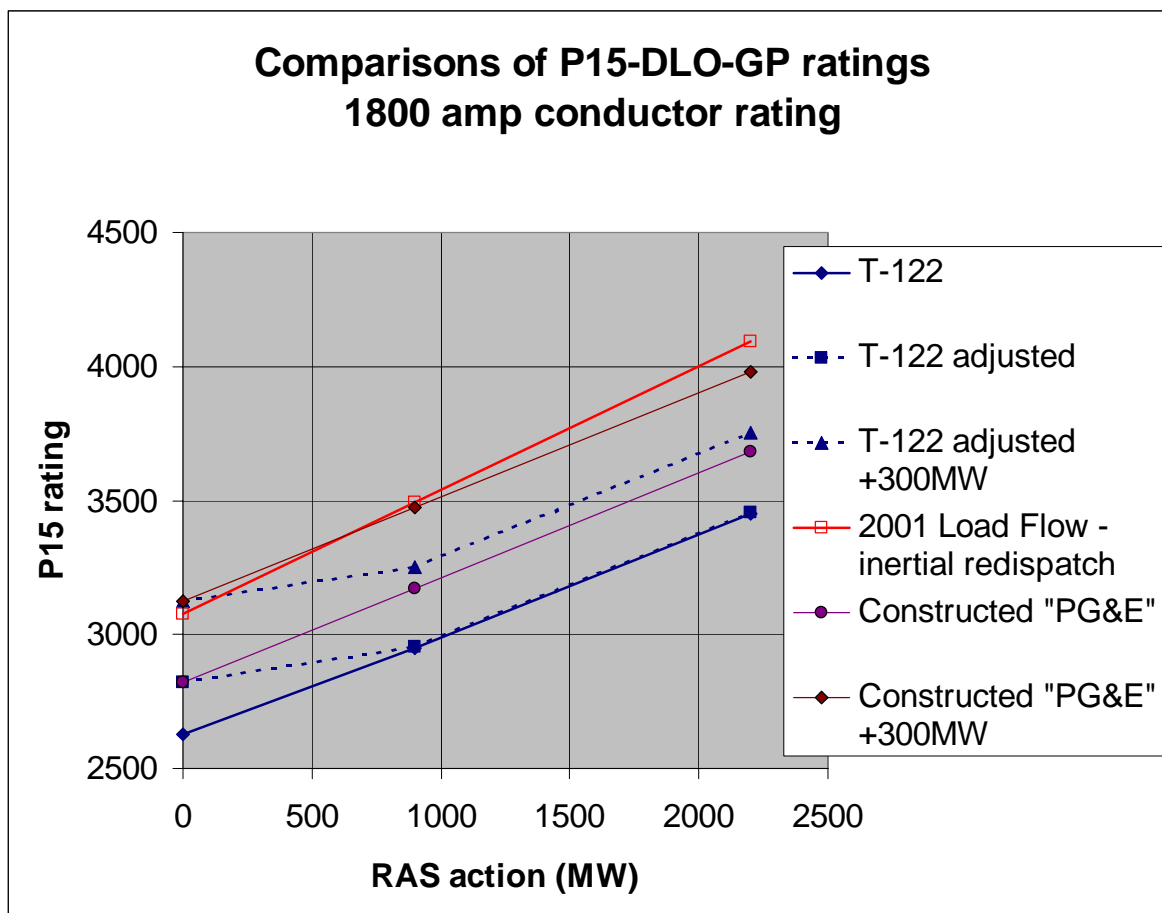


Figure 6. Impact of RAS Action on P15-DLO-GP Ratings

a) Comparison of calculated ratings with ratings published in CAISO Operating Procedure T-122 and ratings derived from PG&E study results.

3.9. Benefits of Real Time Rating Systems

The Path15DLR software of the RTRS will supply a value for the P15-DLO-GP rating that reflects the real time value of armed RAS, environmental conditions impacting conductor temperature, and load and generation patterns. Therefore, the 300 MW adder presently used in T-122 will be replaced by seamless changes in the P15-DLO-GP rating reflecting significant changes in load and generation patterns as they occur. The RAS impacts would be included in a way that is compatible with the present procedure.

4.0 Path Management Software Development (Task 2.3)

4.1. Real Time Data Collection from Field Monitors (Task 2.3.1)

The outline of Real Time Data Collection process has already been described in "Collection of Physical Information about Path 15 (Task 2.2)". Tasks 2.3.1 and Tasks 2.2 are essentially parallel tasks, with the same basic data analyzed for two different end purposes.

Examples of collected and analyzed data are shown in Attachments B1 and B2 and discussed later under Tasks 2.3.2 and 2.4.

4.2. Development of Software Requirements (Task 2.3.2)

A Requirements Specification Document (RSD – Attachment F0) was written in May 2001, based on work in Task 2.3, for a client/server-based software application that will calculate power flow limits for the Path 15 interface based on the real time monitoring of tension in the Gates-Panoche 230 kV line and real time measurements of the line flows on the 230 kV and 500 kV circuits comprising Path 15.

As a result of this calculation, the system operator will know the maximum safe pre-contingency Path 15 power flow as a function of weather conditions along the Gates-Panoche line and present load and generation patterns.

The contingency considered in this document is that of a simultaneous double line outage of the Los Banos-Gates and Los Banos-Midway 500 kV lines (herein after referred as Los Banos South DLO). This will be the only outage evaluated in the computations in this project.

The proposed software system is called "Dynamic Thermal Rating for Path15" or "DTRPath15". Power Delivery Consultants, Inc. was responsible for providing the necessary system and physical data and for the overall modeling of the relationships between the thermal behavior of the Gates-Panoche line and the Rating of Path 15.

The DTRPath15 application was designed according to this document to collect data from external programs and devices and to perform computations using this collected data. The system will allow the user to customize the conductor parameters and configuration information like the minimum, maximum, and default values.

Overall Description

The initial implementation of DTRPath15 will be a client/server application. The system will have the following components:

1. Data Importer - Data collecting module
2. Path limit Calculator - Calculation module
3. User interface
4. A data store

The DTRPath15 application will collect the following data from external systems in "real time":

Line tension, “weighted” steady-state line rating, and solar temperature from the CAT-1 monitoring system at an interval of approximately 10 minutes.

Electrical data (line flow MW values of all lines on Path 15) from the SCADA system at an interval of less than 10 seconds.

A system-state identifier that identifies the present system configuration that defines which set of precomputed distribution factors shall be applied.

Generation ramping data sets that include the onset time, the generation change rate (MW/min), and the total generation change (MW) for a generator. This will be applied to the Diablo Canyon ramp-down scheme and can be applied to other generators as well.

RAS identifier and two MW values representing armed and maximum available RAS for each RAS action. The RAS identifiers will include all or a subset of the RAS identifiers in the data store.

The DTRPath15 application will provide the following basic functions as a whole:

Import Data

This function will allow the system to import temperature data from the tension monitors, power data from SCADA, and the RAS file using the data-collecting module into the database. Before storing the data in the database, this module will validate the data based on the previous valid data. It will execute as a background process with no user interface. The database will be setup on a Windows 2000 Server running MS-SQL Server 2000.

FTP Server

FTP Server software will be installed on the computer where this application is installed. The FTP software is included with Windows 2000 operating system and is optional software on Windows NT Server. All licensed users of the two operating systems are permitted to use this server software without additional charges. This will help in the transfer of XML files from external systems, even if the external systems have a non Microsoft Operating System. The external systems must have the client version of the FTP software, which is included with most of the popular modern operating systems. This server software will be configured during the installation of the application based on customer’s environment and requirements.

Configuration & Conductor Parameter

This function will allow the user to modify the conductor parameters and other configuration information related to minimum, maximum, and default values. These parameters will be used during the path limit computations for DTRPath15. No user interface screen will be provided for this. A commercial package like MS-Access could likely be used as the front end.

Historical Data

To generate historical data, the application will store imported data, computed results, and the application-generated messages (three types - information, warning, and error). The user will be able to view these at any time using the corresponding screens. The application-generated messages inform the user about the health of the entire program.

Perform Calculations

The calculation module using the input data will perform two main types of calculations. The first one will compute the wind speed based on CAT-1 monitor data. The second will compute the maximum possible flow in Path 15 such that the max temperature is not exceeded in the monitored line should the DLO contingency occur. The wind speed calculation will be repeated about every 15 minutes when the CAT-1 data is updated. The Path15DTR limit will be calculated approximately every 30 seconds based on the MW flow data provided by SCADA. Path15DTR limits will be computed for the armed RAS and for all the available RAS. It is to be noted that the calculation module will execute as a background process with no direct user interface. Before every run, this module will pick up the most current data from the database, perform the computation, and store the results in the database.

Input and Output Displays

The application will display input and output data using the following views:

1. Event Log – Application messages will be displayed using Windows 2000 Event Viewer that is included as part of the operating system. The major advantage of using the EventLog is that commercial software packages are available, that when configured, can trigger actions like:
 - Send an email message
 - Call a Telephone
 - Call a Cell Phonebased on the message reported to the EventLog.
2. Historical Data View – This window will display the trend over the last 24 hours. It will display three MW values for Path 15: Total measured flows on Path 15, the Path 15 limit when RAS is armed as specified (this value will be computed), and the Path 15 limit when all available RAS is armed (this value will be computed). This will be the view that will display the results. The system-state will also be displayed.
3. Configuration View – This view will not be created as part of this application. A commercial tool like MS-Access or MS-SQL Server's enterprise manager will be set up at the customer's location to view and modify the configuration information. MS-SQL Server's Data Transformation Service (DTS) will be used to load DTRPath15's system data from ASCII and/or spreadsheet files. DTS supports a wide variety of formats to import and export data from and to.

4.2.1. User Characteristics

DTRPath15 will be designed to work in the background where the user and his or her representative will supply the configuration and conductor parameters. While the system will be delivered with an easy-to-understand user manual, it is assumed that a typical user of the DTRPath15 application will have a reasonable level of technical knowledge.

4.3. System Interface Requirements

The user interface will be consistent with other standard Windows-based applications.

The minimum computer configuration for the application server is:

- Intel Pentium III CPU, 500 MHz-based computer
- Operating System: Windows 2000 Server (with the latest Service Pack applied)
- 256 MB RAM
- 200 MB available hard disk space
- Monitor with 800x600 resolution
- One CD-ROM drive

The minimum computer configuration for the database server is:

- Intel Pentium III CPU, 500 MHz based computer
- Operating System: Windows 2000 Server (with the latest Service Pack applied)
- 512 MB RAM
- 400 MB available hard disk space (More space will be required as the size of the database grows) with a RAID disk
- Monitor with 800x600 resolution
- One CD-ROM drive

4.4. Approach to Implementation

The proposed system will work on NT 4.0, 2000, or later. The required components will be developed using Microsoft Visual C++ 6.0 and ATL-COM. All the data for the program will be stored in MS SQL Server 2000 based database. The basic system architecture is shown below in Figure 7.

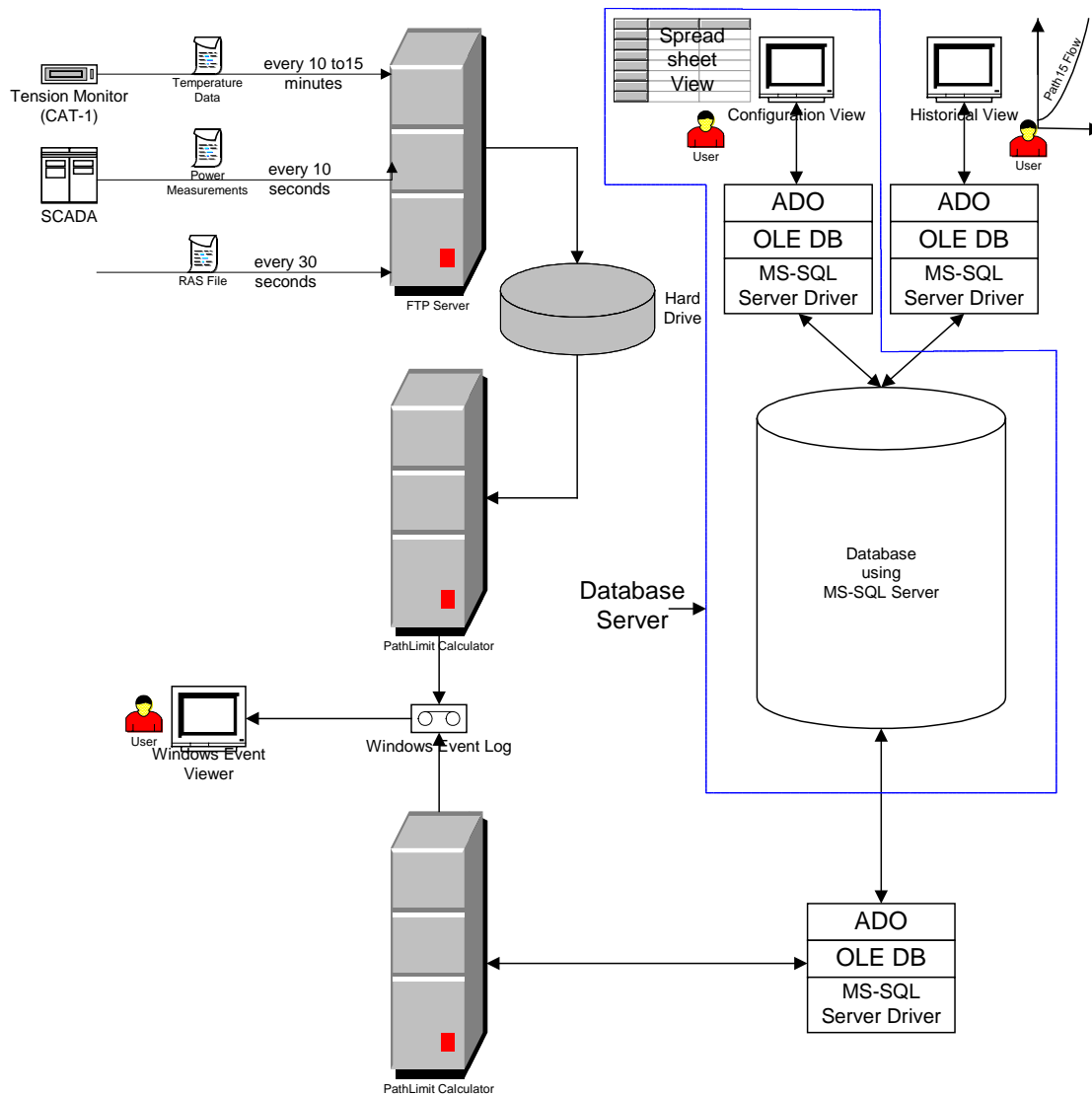


Figure 7. System Architecture

The Data Importer and Path Limit Calculator will be designed as two separate NT service applications. An NT service application normally does not have a user interface. The only interface it has is supplied by the operating system as shown in Figure 8. From this interface the user can start, stop, pause, and resume the service application. A similar interface will be available for the Path Limit Calculator. The FTP Server is included with the server operating system.

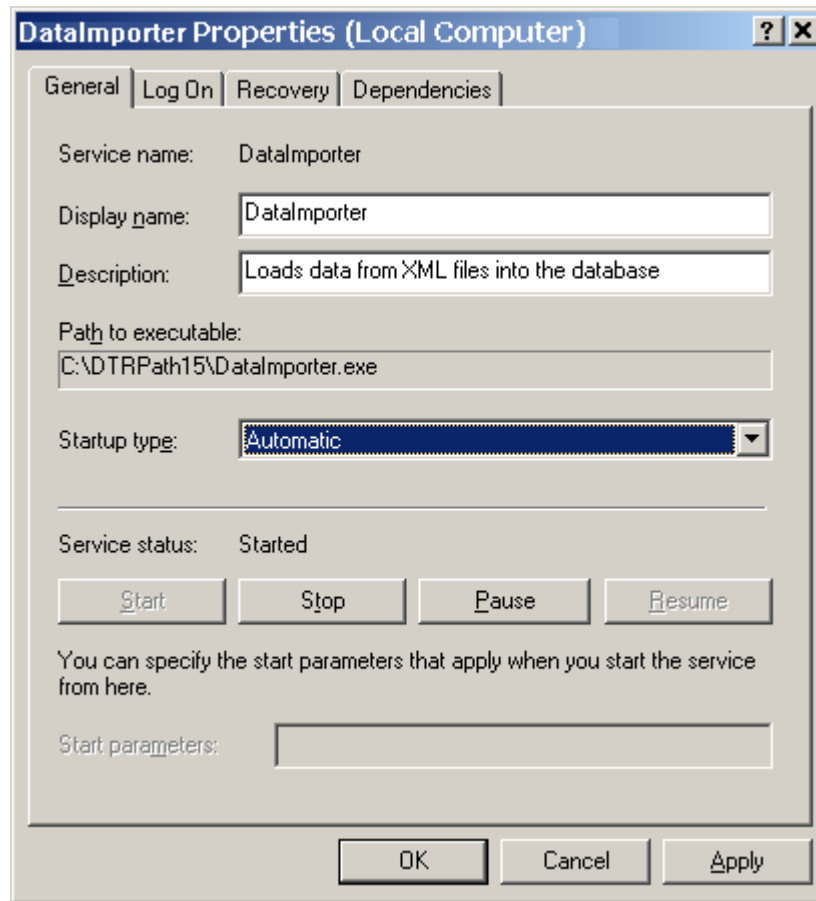


Figure 8. Data Importer Property

4.4.1. Field Software Test Plan

The Field Software Test Plan was developed in August, 2001. The objectives of this test plan were to define the responsibilities and the tasks for the various parties involved in testing. The Test Scripts for testing all the requirements involved in the specification document above were outlined in the document.

The complete Software Test Plan and the related scripts are in Attachments F1-F4. The software design document is in Attachment F5.

4.4.2. Factory Test Report

In the months of September 2001 and October 2001, subcontractors Power Delivery Consultants, Inc. (PDC) and Best Systems, Inc. (BEST) worked with Pacific Gas & Electric (PG&E) to remove minor software problems which cause occasional errors. In particular:

On September 6, PDC sent an update of the the power transfer distribution factors to PG&E based on some modeling questions by Dag Reppen of Niskayuna Power Consultants (NPC) and Dale Douglass (PDC). New values were equal to the old values divided by 0.7744, reflecting

previous confusion about total and path flows. A few days later, PDC sent an additional update of certain other system flow ratios reflecting the resolution of a misunderstanding between PDC and PG&E regarding the sign of MW flows on the 500 kV lines. Prior to this change, we noted some cases where the Path15DLR software seemed to give erroneous results. We determined that this is because the sign of MW flows on the 500 kV lines supplied by SCADA to the program is normally negative (flow into the Los Banos bus from the lines). We had assumed all the flows to be positive in deriving the program.

Starting in September 2001, PDC and BEST worked with PG&E to resolve periodic program halts. During this time, we suggested that it would be much easier to resolve software problems in the Path 15 software were we to gain remote access to the Path 15 workstation. PG&E was not able to allow this due to heightened security concerns. In late September, a series of software investigations solved all outstanding problems. PDC worked with BEST during this period to review some low current logic problems and in inserting a default wind speed for low currents.

In early October 2001, the software seemed to be working without error and the project reached a point where the software was working well enough to allow for a review of the rating predictions by PG&E personnel.

During the remainder of October 2001, PDC worked with BEST to resolve minor errors in Calculated Effective Wind Speed and Air Viscosity which were the result of natural convection equations and acceptance of negative CAT-1 NRS values, and changed the algorithm where we attempt to converge to a Path 15 rating within a reasonable number of iterations.

Finally, on October 23, 2001, BEST sent version 1.0.0.8 of Path15DLR software and version 1.0.0.9 of the database to PG&E for installation. This update resolves all the bugs seen so far and reduces the size of the database such that this database has only the required data.

5.0 Path Management Software Deployment (Task 2.4)

5.1. Field Integration and Field Tests (Task 2.4.1)

The developed and debugged version of Path15DLR software was installed and functional at PG&E end of October, 2001. This started an extensive period of testing, during which several minor modifications were incorporated in the final algorithms.

Data has been collected from the Path15DLR program at 1-2 week intervals. After approximately 1 month, the databases must be emptied to prevent the file sizes from becoming unmanageable. After approximately 1 month, the number of results will exceed 100,000 points, well over the capacity of software used for analysis.

The data collected was analyzed to assure the accuracy of the calculation method and to assess the dynamic rating performance of Path 15. In addition, random points were selected and compared to hand calculations to ensure that no software quality issues were encountered. None were found after the initial installation and testing.

The current “static” ratings for Path 15 are coarsely adjusted for ambient temperature and for RAS level. The ratings were determined for three ranges of ambient temperature and three RAS levels, giving a total of 9 static ratings. These ratings are summarized in table 2.

| | RAS Level | | |
|--|-----------|---------|---------|
| Temperature | 0 MW | 900 MW | 2200 MW |
| T<62°F day or T<71°F night | 2625 MW | 2949 MW | 3532 MW |
| 71°F<T<90°F day or 62°F<T<105°F night | 2550 MW | 2874 MW | 3409 MW |
| T>90°F day or T>105°F night | 2275 MW | 2600 MW | 3250 MW |

Table 2. Path 15 Static RAS Ratings

These static ratings for zero MW RAS were then plotted against a plot of 90%, median, 10% and average of the daily cycles of the path ratings. These plots are shown below for the Path 15 ratings calculated using the armed RAS levels and the available RAS levels. Note that calculated ratings are lower in some cases than the static ratings. Also note that these calculated ratings are not necessarily for zero MW RAS. However, given that the Path 15 ratings increase as the RAS level increases, any encroachments by the calculated rating versus the static rating would also be seen at the higher RAS levels.

Analysis based on two sets of data is used in the graphs shown in Figure 9 and Figure 10. The first set is from March 11-29, 2002 and the second set from January 9-21, 2003. For the majority of time, the lines were either very lightly loaded (below the 200 A threshold at which the software reverts to static backup ratings) or moderately lightly loaded (less than 1/3 of static rating). Under such conditions the line rating results tend to be low, because of the conservative nature of the rating process. Further, the software still operates with the 2002 calibration coefficients (3rd degree polynomial), which tends to give lower ratings than the recently updated coefficients (4th degree polynomials). Neither one of the comparison periods represent a time at which Path 15 was a significant economic constraint.

Path 15 Transfer Limit w/ Armed RAS

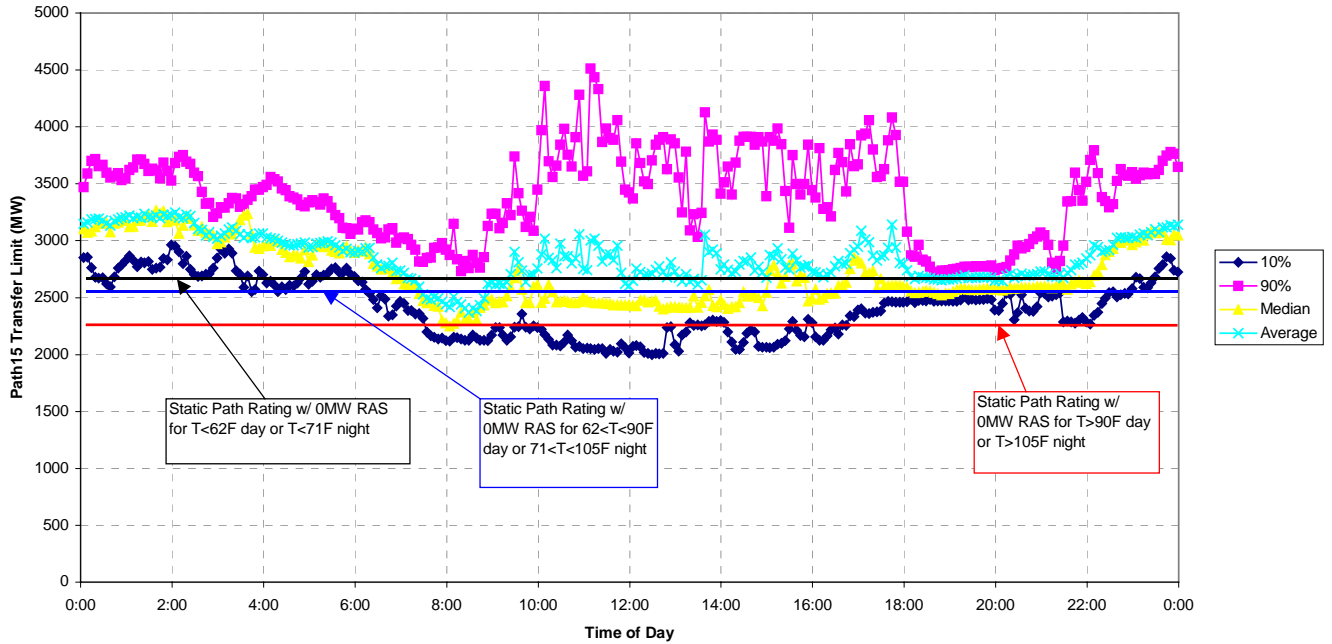


Figure 9. Data - March 11-29, 2002

Path 15 Transfer Limit w/ Available RAS

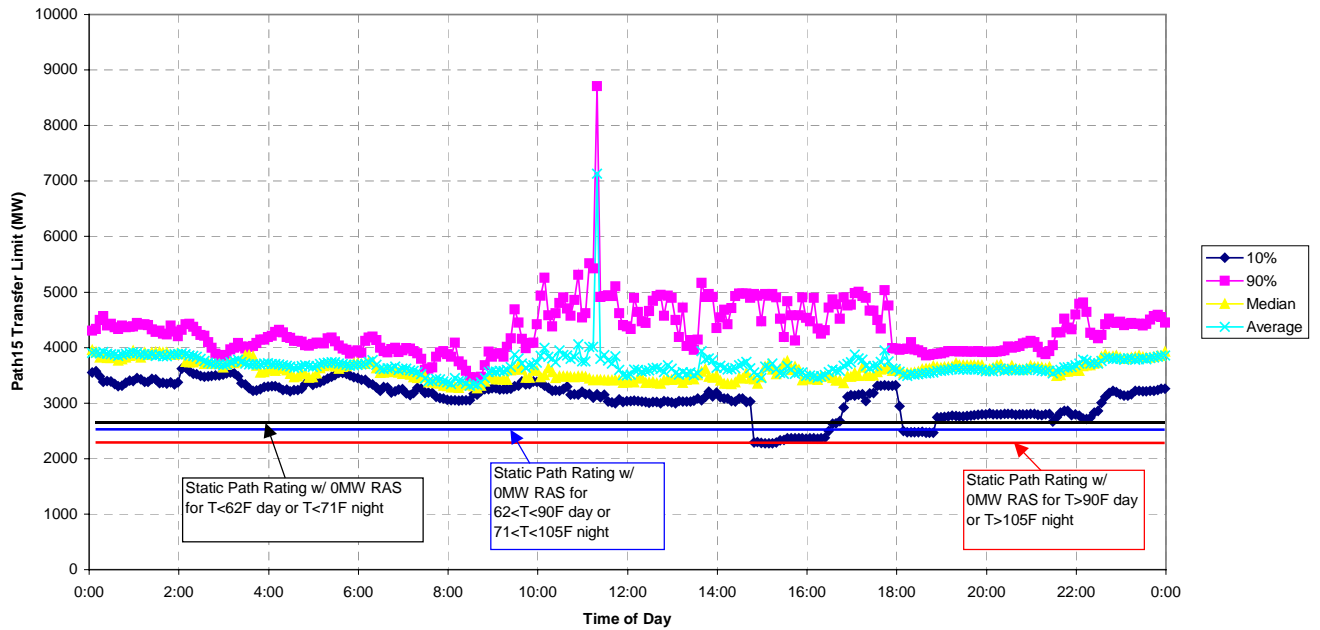
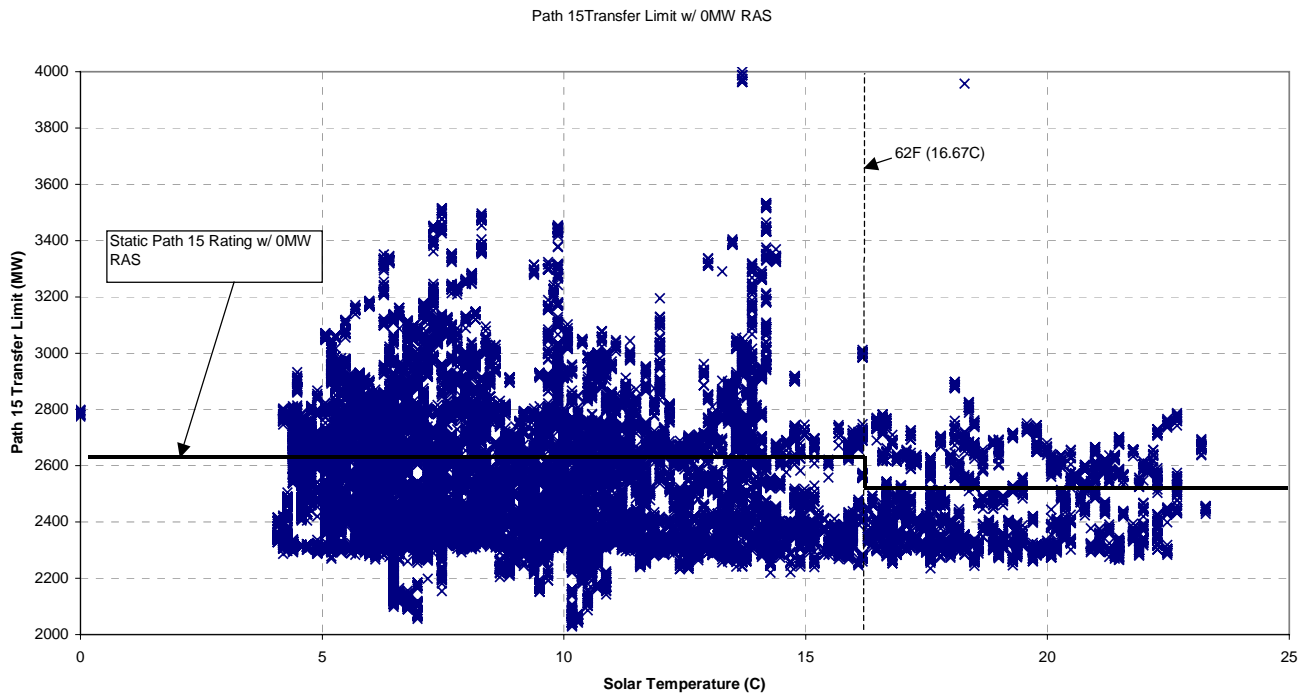
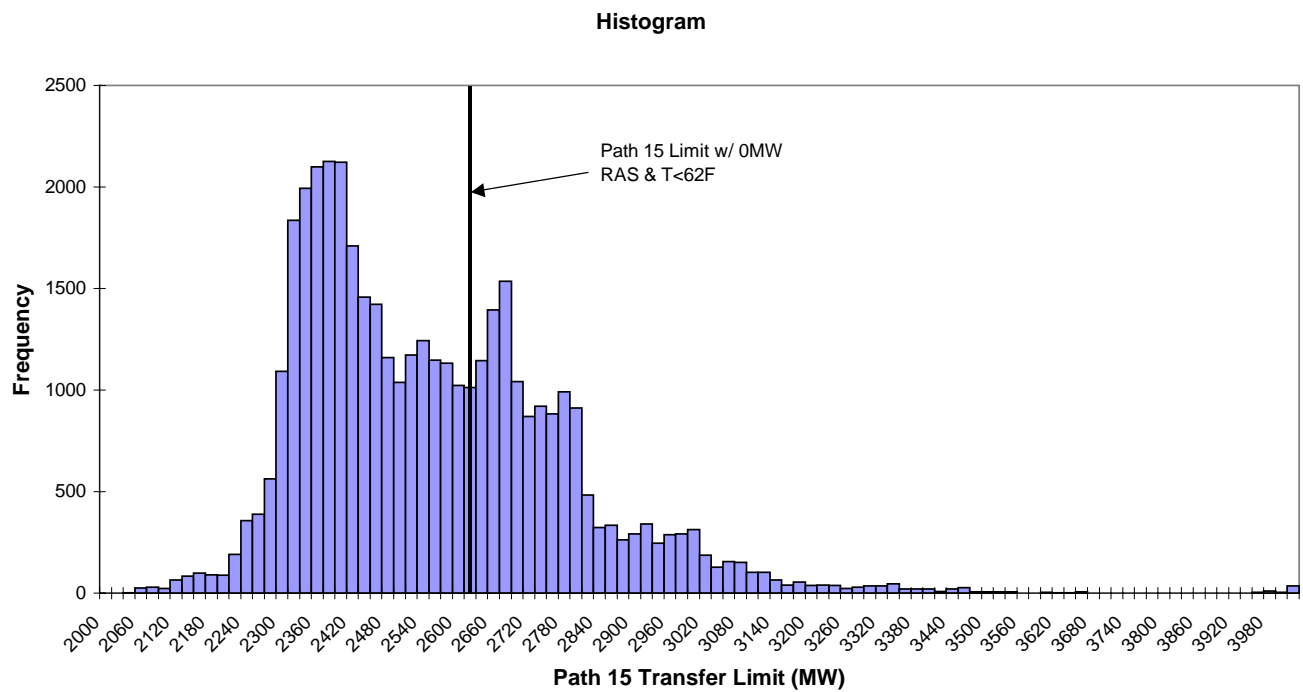


Figure 10. Data - January 9-21, 2003

A more meaningful comparison of the calculated Path 15 rating versus the static Path 15 rating was accomplished by selecting data from a period where there was 0 MW RAS reported. Approximately two weeks of such data was collected and analyzed. With the RAS level fixed at 0 MW, the static rating is now only a function of ambient temperature. Plotting both the static rating and the calculated rating for this period versus ambient temperature produces the



following plot.



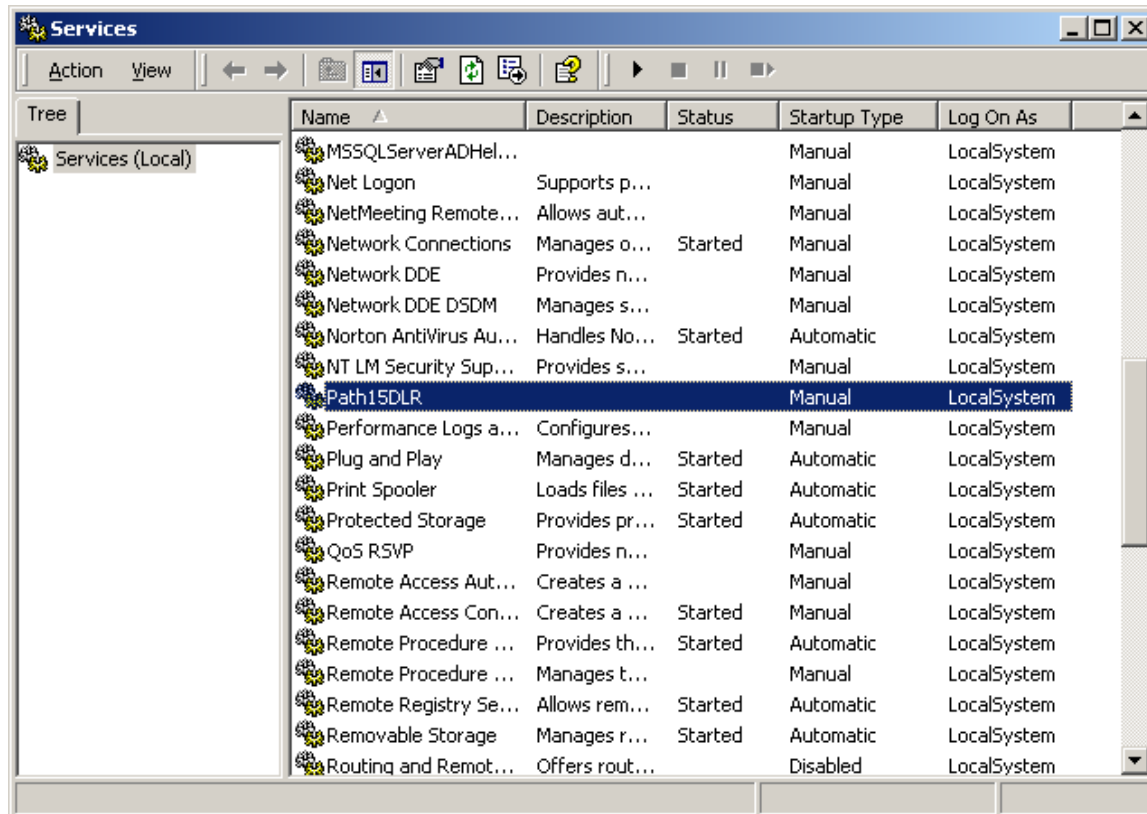
Figures 11-12. Calculated Path 15 rating versus static Path 15 rating.

Examining the plot in Figure 11 and the histogram in Figure 12, it is even more apparent that the calculated Path 15 rating is below the static rating in several instances, outlining the need for a more dynamic approach to rating the Path 15 power transfer. In addition, it can also be seen that the calculated Path 15 rating exceeds the static rating for significant periods of time. These points above the static rating represent additional capacity that could be utilized.

As noted above, the data analysis is only qualitative. A quantitative analysis of path capabilities and economic benefits of real time ratings would require a more extensive study and evaluation of data during periods in which Path 15 represents severe economical constraints.

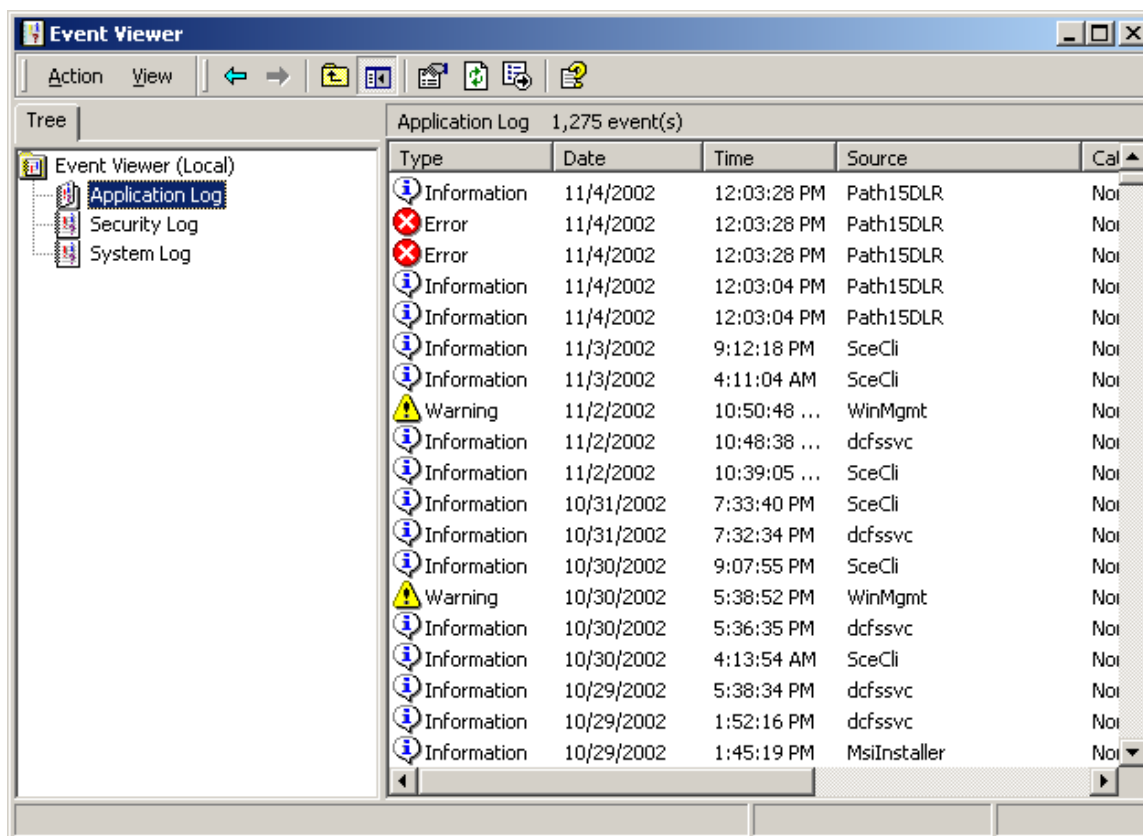
5.1.1. User Guide Document

The Path15DLR 1.0 software has no custom user interface. The software runs as a Windows NT service in the background and operates on a MS-SQL database. Control of the Path15DLR service is done via the standard Windows interface. Select "Services" from the "Administrative Tools". "Administrative Tools" can be found in the "Control Panel". Look for the entry named "Path15DLR" as shown in the figure below. From this dialog, the service may be started, stopped, and set to run automatically.



Messages regarding the operating status of the Path15DLR service may be found in the Application Log. The Application Log may be viewed by selecting “Event Viewer” from the “Administrative Tools”. In the left hand pane of the Event Viewer, select the “Application Log”.

Messages pertaining to the Path15DLR service are those with “Path15DLR” listed as the source. The actual message may be viewed by double-clicking the entry in the Application Log.



The results of the calculations are found in the database table called “Path15Results”. Methods for viewing and working with this data are beyond the scope of this manual. Definitions of the data elements contained in this table can be found in Section 5 of the document entitled “Requirements Specification Document for Path15 Dynamic Line Rating (Path15DLR 1.0)” dated January 4, 2002.

5.2. Seek Utility Acceptance for Real Time Ratings Approach (Task 2.4.2)

Because of the extremely critical nature of Path 15 regarding the reliability of the whole WECC transmission system, it was anticipated that securing the acceptance of PG&E, CAISO, and other related entities for full operational use of the system would be gradual and potentially extend beyond the time frame of the project. It was also anticipated that the full operational use

of the system would only occur if the system conditions in California were so severe that additional capability from real time ratings approach would be of extreme importance. The latter condition has not materialized during the project timeframe. Nevertheless, the understanding of the benefits of the system has reached the level that future operational application is likely in 2003 or 2004.

Several meetings were held with the most important and involved parties, PG&E and CAISO. In these meetings it was found that while there was a general agreement that the most important and primary limitation was the Gates-Panoche circuits, as monitored by Path15DLR, there is no clear agreement on what is the next physical limitation and the level at which this limitation becomes critical.

5.2.1. Transformer Limits

One of the clearly identified next level limitations is the thermal limit of the Gates 500/230 kV autotransformer banks. It was found that CEC had available funds from EPRI cofunding, which could be utilized for investigation and software development to support Path 15 real time ratings projects to include also transformer ratings. The goal of this project is to extend the real time Path 15 rating methods to include the real time thermal rating of the Gates 500/230 kV power transformer and to evaluate other advantageous applications of this transformer rating technology in the California transmission system.

EPRI has developed sophisticated software (PTLOAD and DTCR) for the real time thermal rating of power transformers. The underlying algorithms used in the EPRI software are based on IEEE 57.92-1995 and on IEC 357. Field test results at several locations indicate that power transformers can be safely operated at higher power levels if ratings are based on real time air temperature and loading rather than on worst-case conditions. These test also indicate that monitoring of transformer temperatures and cooling equipment operation is crucial to safe operation.

This project investigates combining the existing EPRI dynamic thermal rating technology for real time transformer rating with the existing Path 15 real time rating software in order to allow higher Path 15 rating levels. The EPRI software will be linked to the Path15DLR software.

The transformer rating project was started in 2002 and is ongoing.

5.2.2. Other Limitations

A meeting on May 29, 2002 listed a number of other possible constraints which all could affect the dynamic limit of Path 15. These included:

1. Overall system considerations such as reactive margin, voltage deviation, and West of Borah limits. These limits would require additional planning studies by CAISO.
2. Thermally limiting transformers and other circuit elements:
 - Gates 500/230 kV transformer (see above)

- Los Banos 500/230 kV transformer
- 500 kV series capacitors

The protection of these elements and their contingency ratings can possibly be improved by the related DTCR project (see above).

3. Other potentially limiting circuits, which share part of Path 15 flow under contingency conditions. These include:
 - a) Gates-Henrietta 230 kV lines
 - b) Metcalf-Moss Landing 230 kV lines
 - c) Midway-McCall circuit
 - d) Midway-Arco and Arco-Gates circuits
 - e) Gregg-Bellota circuit
 - f) Los Banos-Westley circuit

PG&E has already installed monitoring equipment on a. and b., has purchased equipment for c. and is considering d. Equipping the remaining circuits with monitors would be a relatively low cost project, although linking the data to Path15DTCR may be complicated.

In addition to the above, CAISO has provided the following requirements for operational use:

1. Validation of rating calculations by CAISO.
2. Redundancy of equipment.
3. User interfaces extended for engineers and dispatchers.
4. CAISO visibility of data (available through data links from PG&E).
5. Operating procedures which address failures of Path15DLR system.
6. Training of engineers and dispatchers.
7. WECC approval.
8. 8. Demonstration period in parallel with existing system.

The above processes are beyond the scope of current CEC project, which is related to demonstration of the feasibility of real time transmission ratings of Path 15.

The main contractor has prepared several documents and presentations which can be used to further assist in achieving utility acceptance of the methods. These are included as attachments G1-G3.

6.0 Feasibility Study on the Implementation of the Real Time Ratings Approach to Other California Paths (Task 2.5)

6.1. Overview

Task 2.5 required the contractor to identify at least two additional paths in California which are suitable for real time ratings approach and to identify the benefits. The contractor was then expected to perform a cost-benefit analysis for these paths.

Initially, it was hoped that identification of limiting paths or circuits, and their cost justifications could be determined based on information from CAISO. After initial meetings with CAISO, it became apparent that these definitions could only be derived from individual utilities' data and their specific justification criteria.

Further extensive discussions with utilities have shown that direct cost/benefit relationship is only one of the justifications for real time rating systems. Other system benefits are sometimes of equal or higher importance. Additionally, there are significant differences in the positions between different utilities. These differences will be discussed below. Exact details of these internal justification calculations cannot be made available, because they typically contain information which the transmission owners consider proprietary or confidential. On request, contact information for interviewed utility persons can be provided.

Nevertheless, the actual progress of implementation has progressed in several California utilities well past the feasibility study phase. The importance of real time ratings is proven by the fact that some of these utilities are installing substantial real time rating systems with their own funds. These applications generally parallel the contingency rating methods of the current CEC study, yet in a substantially simplified manner.

The real time ratings approach of this CEC project is limited to contingency ratings. Ratings use in economy power transfers and in conjunction with voltage and stability limits were outside the scope of this study, as was the forecasting of ratings. These applications could have substantial economic importance. Further funding from CEC is sought to support such studies.

6.2. Justification Process and Acceptance

There are, at present, 132 CAT-1 operational real time monitoring systems at 33 utilities around the world. Of these, 30 are in California. PG&E has 18 operational CAT-1 systems, plus 6 in various stages of installation on a total of 13 circuits. SDG&E has 2 CAT-1 systems on two circuits in operational trials. SMUD has recently acquired 4 CAT-1 systems for two circuits.

To a large degree, the justification of real time rating systems depends on local or regional conditions. A key factor within these conditions is the regulatory treatment, especially the rate treatment of transmission line rates. If the rates favor effective use of the transmission system, justification of real time ratings is generally clear and straightforward. Awareness of transmission constraints has increased on regulatory and political levels. Recent FERC and DOE documents indicate that incentives on rewarding such efficient use of the transmission system are likely to be upcoming.

Applications at PG&E

PG&E is progressing very rapidly in real time ratings applications. At the time of this report, PG&E has operational systems installed on six 230 kV lines and one 115 kV line in the San Francisco area and on two 115 kV lines in the Central Valley, in addition to the equipment on the four 230 kV lines which are involved in this Path 15 study. Installation of equipment on three additional 115 kV lines is in progress. This makes PG&E the most advanced real time rating user in the world, with a total of 16 lines being monitored.

PG&E conducts a rigorous justification process for determining the justification of funds for real time rating equipment. The following key considerations are parts of the process:

1. Avoiding unnecessary load curtailment.
2. Minimizing cost of generation
3. 3. Protecting equipment in case of overload
4. 4. Improving system security or safety
5. 5. Allowing better scheduling of new construction or system upgrades

Cost justifications can be reasonably accurately derived for considerations 1 and 2 above. Cost justifications are more difficult to calculate accurately for considerations 3 and 5. Nevertheless, based on justifiable and quantifiable factors, PG&E's calculated cost/benefit ratio was 4.8 for a 230 kV project in the Bay Area.

Detailed application principles for real time rating are still developing. One of the most economically promising methods, especially applicable in the San Francisco Bay area, involves relaxing the minimum wind speed assumption from 2.0 ft/sec to 4.0 ft/sec for emergency rating calculations. Planning studies indicate that a substantial number of circuits are going to exceed their first contingency limits in the near future by 2-10%. If the wind speed assumptions are changed to 4 ft/sec, these circuits will typically have a 15-25% increase in ampacity.

On several of the lines studied, the 4 ft/sec+ assumption seems to have a probability of 95-98% at the time of the anticipated peak loads. PG&E is planning to use this higher planning rating, but only if the lines are equipped with real time monitors. Thus, if the contingency occurs under the exceptional conditions of low wind speeds, the operator can proceed with corrective actions without endangering line safety and system security. The economic result is the possibility of avoiding or postponing expensive line constructions and/or upgrades.

San Diego Gas & Electric

San Diego Gas & Electric (SDG&E) is conducting trials of real time ratings on two circuits. The primary objective of these trials is developing the methods for increased contingency ratings of the lines. Because the studies are ongoing, there is not yet a clear justification method for the applications. Another application being considered is real time ratings on interties. This is a more complex situation and would most likely require development of predictive software.

Sacramento Municipal Utility District

Sacramento Municipal Utility District (SMUD) has purchased real time rating equipment (using their own R&D funds) for two lines to the American River hydro power plants. The driving motive in this case is that the three lines to the hydro plants have barely sufficient capability during certain operating conditions. The operating problem becomes significantly more difficult if any of the lines are undergoing maintenance, which may result in uneconomic dispatch as well as lost revenue opportunities. Furthermore, the maintenance limitations become critical during the times when environmental restrictions need to be observed regarding minimum and maximum flow requirements.

SMUD is also interested in the cofunding of future CEC studies, if they coincide with subjects which are of interest to SMUD.

Western Area Power Administration

Western Area Power Administration (Western), Sierra District, is considering application of real time ratings on several lines in the Sacramento area. Because this project deals with a substantial research issue, funding assistance is sought from CEC.

Western's motivation is to avoid special protection schemes of generation resources, especially related to thermal limitations of O'Bannion-Elverta and related circuits. Under the present situation, a thermal overload on these circuits causes running back of generation in the area typically reducing voltage and bringing the system closer to voltage collapse limits especially if any line outages occur in the area.

In addition to being the potential cause of voltage collapse, the thermal limitations will also cause direct economic consequences. If local generation is reduced, power has to be imported from outside the area, usually at a price premium compared to local generation.

Real time thermal ratings and related predictive software are expected to significantly mitigate these constraints.

Wind Power

Recently, a consultant has brought a potential application to our attention, related to the 115 kV lines serving a wind generation area. The wind generation in the area is limited by the 115 kV system, and is subject to Congestion Procedures of CAISO. The evaluation of the application is progressing and may lead into real time monitoring in the spring of 2003.

The Valley Group, Inc. has significant experience with similar applications. In general, lines to wind generation sites almost always have significantly higher capability during high generation conditions than what is shown by normal static ratings. For example, in a case of a wind farm in Texas, the maximum output of the generation was limited to 170 MW based on static rating of the lines. Real time installation monitoring has indicated that the wind farm capability could be increased by 20% with zero congestion constraints and by up to 35% with 1-2% probability of constraints.

This type of application could have substantial benefits for renewable resources elsewhere in California as well. Wind farms are generally located in remote areas with relatively weak transmission capabilities. Recent experiences have shown that the upgrading of transmission networks in such areas can be a contentious issue. If the line capabilities could be increased without substantial physical upgrades and by minimum costs using real time rating methods, wind generation could be economically more attractive.

More detailed information is included in Attachments H1 and H2.

7.0 Conclusions and Recommendations

7.1. Conclusions

- The project has proven that real time ratings are a feasible method of improving the capability of Path 15, under the most critical operating conditions. Thus, real time ratings of Path 15 could result in significant energy cost savings.
- The CAT-1 Transmission Line Monitoring Systems used have been shown to be robust and stable during the two year period of operations.
- The DTRPath15 software has been shown to operate reliably over the extended period of trials. The calculated dynamic ratings have been shown to be reproducible by independent spot checks.
- The dynamic rating data indicates that the present assumed line ratings are generally conservative during the periods of highest loads on Path 15 (winter nighttime), but that they may not be conservative enough during summer daytime. On the other hand, high loads during summer daytime are extremely unlikely under present economic and supply conditions.
- The developed software is Path 15-specific. While the intellectual information gained from the application is significant, the software itself has no identified commercial potential at other identified locations.

7.2. Benefits to California

- The potential benefits of the project to California depend on the acceptance of the developed software by CAISO. The total constraint cost of Path 15 amounts to tens of millions of dollars annually. Even limited use of the developed software could result in multi-million dollar annual savings.
- PG&E and CAISO are working to address the above additional limitations issues. It is also expected that, after a prolonged period of testing, the software developed in the project will result in actual real time operation.
- The technical success of the project has resulted in a number of additional real time rating applications in the PG&E system. Other California utilities are planning real time rating trials on a number of lines in 2003 and 2004.

- The project has resulted in the cleared definition of other potential limitations of Path 15. Some of these constraints are already being addressed.

7.3. Recommendations

- The required steps for full benefits from the project are development of application procedures, operational parallel testing, operator and dispatcher training and, possibly, increased redundancy of systems on the path. These steps should be undertaken by PG&E and CAISO.

8.0 References

1. CAISO Operating Procedure No. T-122A and T-122, West of Borah versus Path 15 Nomograms, 2/14/00.
2. CAISO Operating Procedure No. S319, Real-Time Path 15 South to North Flow Mitigation Procedure, 1/15/99.
3. Dispatching Instruction O-51, Operation of Path 15 RAS Controller, Spring 2000. PG&E, Draft, Revised 3/15/00.
4. Remedial Action Scheme Expansion Project for Remedial Action Internal to PG&E Service Area, Assessment of Scheme Reliability and Security. PG&E, Revised 9/8/98
5. Midway RAS Expansion Project, Assessment of Scheme Reliability and Security. PG&E 9/1/00.
6. WECC Path 15 Operating Capability, Study Report, Spring 2000, PG&E, 2/4/00.
7. WECC Path 15 Operating Capability, Study Report, Summer 2000, PG&E, 4/20/00.
8. 2001 Summer, Path 15 Operating Transfer Capability Increase Study Report, PG&E and CAISO, 4/13/01.
9. CAISO Operating Procedure No. T-122A, West of Borah versus Path 15 Nomograms, 5/8/01.

Glossary

| | |
|------------|--|
| ACSR | Aluminum Core, Steel Reinforced. Power line conductor (cable) type. |
| ACSS | Aluminum Conductor, Steel Supported. Power line conductor (cable) type. |
| BEST | BEST Systems, Inc. Subcontractor for project. |
| CAT-1 | TVG's CAT-1 (originally from "Clearance Assurance of Transmission" - tension monitoring/real time rating to assure safe clearances of the power line conductor from objects on the ground) Transmission Line Monitoring System units measure mechanical tension and selected weather parameters at utility towers, for real time rating of overhead transmission lines. May refer to structure-mounted field units or to overall system, including CATMaster, algorithms, etc. |
| CATMaster | TVG's CATMaster Base Station is the receiving unit for CAT-1 Transmission Line Monitoring System transmissions from utility towers, and provides the interface to the utility EMS/SCADA system. |
| LBS DLO | Los Banos South Double Line Outage, the simultaneous outage of the two 500 kV lines of Path 15. |
| NPC | Niskayuna Power Consultants. Subcontractor for project. |
| P15-DLO-GP | The P15-DLO-GP rating is the maximum power that can be transferred across Path 15 considering the loading of the Gates-Panoche line for the DLO contingency. |
| Path 15 | California's Path 15 is the main transmission interface between northern and southern California. Path 15 is located at the southern part of PG&E's service area, near Fresno. It consists, primarily, of two 500 kV and four 230 kV circuits. |
| Path15DLR | Software developed under project for Path 15 real time path rating. |

| | |
|------|---|
| PDC | Power Delivery Consultants, Inc. Subcontractor for project. |
| span | Distance between two transmission line towers |
| TVG | The Valley Group, Inc. Contractor for project. |

9.0 List of Attachments

- A1: CAT-1 brochure
- A2: CAT-1 Main Unit Specifications
- A3: Load Cell Specifications
- A4: CatMaster Specifications

- B1: Report to CEC and CAISO on static thermal limitations

- C1: Initial Calibration Report
- C2: Final Calibration Report

- D1: Final Report on Physical Limitations

- E1: Final Report on Operating Limitations

- F0: Software Requirements Specification Report
- F1: Path15DLR10 Software Test Plan
- F2: Path15DLR 1.0 Test Script 01
- F3: Path15DLR 1.0 Test Script 02
- F4: Path15DLR 1.0 Test Script 03
- F5: Path15DLR 1.0 Software Design Report
- F6: Path15DLR 1.0 Software Deployment – User’s Guide

- G1: Presentation at T&D Conference –2002
- G2: Presentation at CAISO, June 2002
- G3: Timo Seppa: “Alleviating Constraints on California’s Path 15”

- H1: Feasibility Study on the Implementation of the Real Time Ratings Approach to other California Paths.

H2: Implementation of the Real Time Ratings Approach to other California Paths.
Supplement by Stanfield Systems, Inc.